April 29, 2013

Submitted Electronically Via: RFS@Mail.House.Gov

Honorable Fred Upton
Chairman
Committee on Energy and Commerce
U.S. House of Representatives
2125 Rayburn Building
Washington, D.C. 20515

Honorable Henry Waxman
Ranking Member
Committee on Energy and Commerce
U.S. House of Representatives
2322A Rayburn Building
Washington, D.C. 20515

Re: April 18, 2013, White Paper on Agricultural Sector Impacts.

On behalf of the members of the American Frozen Food Institute (AFFI), thank you for organizing this important and timely review of the Renewable Fuel Standard (RFS). AFFI represents nearly 500 U.S. frozen food producers covering every segment of the $70 billion frozen food industry. This submission comments on questions posed in your April 18, 2013, White Paper on Agricultural Sector Impacts.

1. **What has been the impact of the RFS on corn prices in recent years? What has been the impact on soybean prices? Have other agricultural commodity prices also been affected?**

The committee is currently reviewing the RFS law and implementation to determine whether the RFS is reducing America's dependence on foreign oil and creating an affordable and clean alternative to conventional fuels. Since its enactment in 2005 and subsequent expansion in 2007, experts argue the RFS has failed to meet these goals. According to Susan Dudley, director of the George Washington University Regulatory Studies Center, replacing about 2 percent of the U.S. gasoline supply with biofuels in 2008 cost U.S. taxpayers $4 billion in subsidies. According to researchers at Rice University, this works out to an average taxpayer cost of $1.95 per gallon for each traditional gallon of gasoline substituted with biofuels.

Additionally, food makers are concerned the RFS has driven up the price of corn, a vital ingredient in food and feedstock, since its inception and driven up costs at the grocery store. Under current law, the RFS requires the blending of 13 billion gallons of corn-based ethanol. Corn is both the chief ingredient in animal feed and an ingredient in about 75 percent of all foods in the grocery aisle. Consequently, RFS-induced increases in corn prices drive up the cost of producing a wide range of foods and lead to higher food bills for consumers. AFFI believes food should be used to fuel bodies, not vehicle engines. Trying to change the price at the pump should not burden consumers with increased prices in the grocery check-out aisle.

Approximately 40 percent of all corn grown in the U.S. is diverted for use in ethanol production, an increase of about 15 percent compared to before the RFS was implemented. Based on data from the U.S. Department of Agriculture (USDA), corn prices have increased from an average of $2.54 per bushel at harvest in 2006 to $5.73 per bushel in 2011, 1/ and prices have continued to rise since 2011. USDA-projected season-average corn prices are now $6.65 to $7.15 per bushel, 2/ representing a decrease in projected price due to optimism that the U.S. will experience a more favorable harvest year compared to the harvest during last year's historic drought. These figures demonstrate a 260 percent to 280 percent increase in the price of corn driven substantially by the increased demand for corn due to the RFS.

Corn planted for ethanol is a substitute for other crops that a farmer might plant, such as wheat or soybeans. Therefore, as more land is devoted to corn production to satisfy the increased demand caused by the RFS, less land is planted in competing crops, decreasing the supply and increasing the price of these crops. As the price of corn increases, so does the price of any crop such as wheat, soybeans, specialty fruits, and vegetables that a farmer would otherwise be planting.

Given these considerations, AFFI led a coalition of 13 food groups that expressed support for bipartisan legislation introduced in the U.S. House of Representatives that will protect food makers and consumers from unnecessary food price increases by reforming the RFS. Introduced by Reps. Bob Goodlatte (R-Va.), Jim Costa (D-Calif.), Peter Welch (D-Vt.) and Steve Womack (R-Ark.), the "Renewable Fuel Standard Reform Act" prohibits corn-based ethanol from being used to meet the RFS, and reduces the total size of the RFS by 42 percent over the next nine years. In addition, the bill limits the RFS to using only renewable biomass and other advanced biofuels. We urge the Committee to take action on this bill.

Current biodiesel policy is also having an impact on soybean prices. USDA estimates that the U.S. will dedicate 5 billion pounds of soybean oil to meet the U.S. Environmental Protection Agency (EPA) biodiesel mandates. The 5 billion pounds of soybean oil requires 450 million bushels of soybeans, a level that equates to approximately 10 million acres of soybeans according to agriculture economic analysts at Advanced Economic Solutions. In a recent analysis, George Washington University Regulatory Studies Center Policy Analyst Sofie Miller reported EPA's biodiesel standards will raise the price of soybeans by 18 cents per bushel. The price of soybean oil is expected to rise by 3 cents per pound for food producers who

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[1]/ USDA, Economic Research Service, Commodity Costs and Returns, Recent Costs and Returns: Corn, http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx.

[2]/ USDA, World Agricultural Supply and Demand Estimates, April 10, 2013, http://www.usda.gov/oce/commodity/wasde/latest.pdf.

rely on soybean oil as an essential ingredient. As Congress seeks to potentially reform the RFS to eliminate the corn ethanol mandates, it should also reform the biodiesel mandate or risk continued food price pressure on soybeans caused by the current U.S. energy policy.

2. How much has the RFS increased agricultural output? How many jobs has it created? Have any jobs been lost? What is the net impact on the agriculture sector?

AFFI believes any consideration of the overall impact of the RFS on the agricultural sector must take into account the full effects on the agricultural sector, the frozen food industry and all related and supporting industries.

According to Kent Thiesse, MinnStar Bank Vice President and former educator at the University of Minnesota Extension, "Livestock producers in many areas of the U.S. are not only facing extremely high feed costs, but are also dealing with problems associated with feed availability. The National Beef Cattleman's Association (NCBA) estimates that the 2012 drought, and the resulting low profitability, will lead to liquidation of 500,000 beef cows and 50,000 dairy cows in the U.S. by year's end. The estimated cost of production for pork producers rose sharply in the third and fourth quarters of 2012. Based on hog prices during that period and hog futures prices in the coming months, many experts are now projecting a loss of about twenty to thirty dollars per hog marketed during the six-to-12-month period from July 1, 2012 to June 30, 2013."

As the cost of producing these products increases, overall production would be expected to decrease. An increase in agricultural revenue may be offset by a decrease in revenue and potentially employment elsewhere in the food industry.

3. Was EPA correct to deny the 2012 waiver request? Are there any lessons that can be drawn from the waiver denial?

EPA is authorized under the Clean Air Act to issue a waiver of the RFS if the administrator determines that implementation of the requirement "would severely harm the economy" or that there is "an inadequate domestic supply." Clean Air Act, Sec. 211(o)(7). AFFI believes EPA was wrong to deny the 2012 waiver request.

In the summer of 2012, governors of nine states, along with 26 U.S. Senators and 156 U.S. House members, officially petitioned EPA to grant the RFS waiver. In addition, the request for a RFS waiver was supported by a coalition of 30 food industry trade groups led by AFFI as well as the majority of livestock and poultry organizations. In denying the waiver, EPA indicated that the agency did not find the necessary evidence to support a finding of "severe economic harm" that would have warranted the RFS waiver to be granted.

The RFS continues to impose significant economic harm in 2013 by artificially increasing the price of crops, food and gasoline. EPA's failure to grant the waiver—

the second such instance in recent years (the governor of Texas unsuccessfully petitioned EPA for a waiver in 2008)—casts significant doubt on EPA's ability to properly manage the RFS while giving due consideration to prevailing economic conditions.

AFFI believes the lesson to be drawn is that the two recent attempts to convince EPA to waive part of the RFS to alleviate substantial economic harm demonstrates that the EPA administrator is not managing the program in an economically responsible manner. At a time when USDA was warning that food prices could jump as much as 5 percent, with corn prices up by 45 percent, and the corn crop predicted to be among the worst in memory, it simply made little sense to divert corn to refineries to make fuel instead of food.

In denying the waivers, EPA has interpreted the RFS amendments to the Clean Air Act in a way that creates an impossible standard for any party trying to demonstrate economic harm.

4. Does the Clean Air Act provide EPA sufficient flexibility to adequately address any effects that the RFS may have on corn price spikes?

AFFI believes the two recent attempts to convince EPA to waive part of the RFS to alleviate substantial economic harm demonstrate that the Clean Air Act amendments do not provide adequate legislative guidance to ensure EPA administers the program in an economically responsible manner.

EPA now requires a waiver request provide (1) a showing that implementation of the RFS program itself is the cause of the severe harm; (2) a generally high degree of confidence that the implementation of the RFS "would" severely harm the economy of a state, region, or the United States; and (3) a showing that the potential harm to the economy be "severe," a term never defined. 3/ These showings—especially the near-certainty with which a party is expected to demonstrate the undefined "severe" economic harm and the RFS's causation of that harm—are impossible to make.

5. The Clean Air Act was not intended to require such an impossible standard for a waiver. What has been the impact, if any, of the RFS on food prices?

The RFS has driven up food prices significantly. The current prices of corn and soybeans have reached historic levels, having negative economic consequences on nearly on all segments of the food industry from producer to consumer.

Corn is integral to the food supply, and 75 percent of foods on grocery store shelves contain corn, corn byproducts or corn-processed-foods, or are derived from an animal raised on corn. The National Research Council estimates that a 20

[3]/ EPA Notice of Decision Regarding the State of Texas Request for a Waiver of a Portion of the Renewable Fuel Standard, 73 Fed. Reg. 47168, 47170–72 (Aug. 13, 2008).

percent to 40 percent increase in the price of corn drives corn-based food prices up by 2 percent to 4 percent at the retail level.[4/] USDA's Economic Research Service estimates that on average, a 50 percent increase in corn prices results in an 1 percent increase in overall food prices (including in this average foods without corn in their supply chain). [5/] A 260 percent to 280 percent increase in the price of corn drives up retail prices of corn-based foods by 26 percent to 56 percent, and overall food products by 5 percent to 5.6 percent. AFFI believes the RFS corn ethanol mandate should end because such drastic increases put significant pressure on families struggling to stretch their dollars to keep nutritious food on the table.

According to Farm Econ LLC Economist Tom Elam, since Congress created the RFS in 2005, annual feed costs have increased by 8.8 billion dollars for chicken producers and 1.9 billion dollars for turkey producers. Elam's report also indicates that food production costs increased nearly three dollars for every one dollar of added ethanol production.

Moreover, because the RFS requires that certain levels of renewable ethanol be blended into the motor fuel supply and because corn is the only viable source for this ethanol, ethanol demand for corn is completely inelastic—blenders or refiners are required to purchase the corn no matter the price and will not respond to higher prices by decreasing consumption. The food sector, which uses less than 60 percent of the corn crop, must therefore absorb 100 percent of the increase in corn prices.

Since the expansion of the RFS in 2007, food prices in the U.S. have risen 28 percent faster than inflation, according to data from the Bureau of Labor Statistics and FarmEcon, LLC.[6]

By substantially increasing the cost of food, the RFS has a harmful secondary effect on the workers and industries reliant on the food sector for their livelihoods. Higher prices can lead to decreased production and the need for fewer workers or fewer shifts, creating a ripple effect through the economy.

6. What role could cellulosic biofuels play in mitigating the potential effects of the RFS on corn prices?

There was no commercial cellulosic biofuel produced in 2007 when the RFS was created, virtually zero commercial cellulosic biofuel was produced in 2012, and zero commercial cellulosic biofuel is projected to be produced in 2013. Cellulosic biofuel

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[4]/ Committee on Economic and Environmental Impacts of Increasing Biofuels Production, National Research Council, *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy* 133 (2011), http://www.nap.edu/openbook.php?record_id=13105&page=1.

[5]/ USDA, Economic Research Service, *Food Price Outlook: Highlights*, http://www.ers.usda.gov/data-products/food-price-outlook/highlights.aspx; Hibah Yousuf, *Corn Price Spike: Food Inflation a "Real Threat*," CNN Money, July 18, 2012, http://money.cnn.com/2012/07/18/investing/corn-prices-food-inflation/index.htm.

[6] *See* Dr. Tom Elam & Sr. Steve Meyer, *Feed Grains, Ethanol and Energy – Emerging Price Relationships* (Dec. 13, 2010), http://www.farmecon.com/Documents/12-13-2010%20Corn%20Price%20S-U%20Ratios%20Elam-Meyer.pdf.

theoretically could develop to offset the use of corn on ethanol production. However, as the past six years have demonstrated, the progress of cellulosic biofuel must be measured in terms of decades, not months or years.

Ethanol manufactured from non-food "cellulosic" feedstock will only begin to be cost competitive with corn-based ethanol by 2016, according to an industry survey conducted by Bloomberg New Energy Finance. In the near future, cellulosic biofuel has no potential to meaningfully impact U.S. motor fuel supplies or the effects of the RFS on corn prices for years. AFFI believes ending federal mandates that artificially support the use of corn in ethanol manufacturing is the only way to allow the market to dictate the growth of the use of cellulosic biofuels.

7. What impact are cellulosic biofuels expected to have on rural economies as the production of such fuels ramps up?

As explained previously, a commercially viable cellulosic biofuel industry has failed to develop over the past six years despite aggressive targets and significant economic incentives due to record-high corn prices.

8. Will the cellulosic biofuels provisions succeed in diversifying the RFS?

Experts in the refining industry indicate that cellulosic biofuels have failed to achieve any commercial success despite substantial regulatory and economic incentives. History has shown that the RFS is not the appropriate tool to spur a cellulosic biofuel industry. If Congress wants to explore ways to promote this industry, it should phase out the RFS and focus on approaches that do not tax a key food commodity in an attempt to jumpstart this new industry. AFFI believes ending federal mandates that artificially support the use of corn in ethanol manufacturing is the only way to allow the market to dictate the appropriate growth for cellulosic ethanol.

9. What is the scale of the impact of the RFS on international agricultural production and global land use changes?

AFFI agrees with economic findings that the RFS creates significant incentives for global agricultural production and land use to align in an inefficient manner. Currently, the RFS diverts 15 percent of the world corn supply from food to fuel, putting upward pressure on food prices. If the U.S. produces 16 billion gallons of ethanol equivalent cellulosic biofuels by 2022, 30-60 million acres of land might be required for cellulosic biomass feedstock production, thereby creating competition among land uses, according to a paper by the National Research Council.[7]

A recent Tufts University study estimates that U.S. ethanol expansion during the past six years cost more than 5.5 billion dollars in higher prices for corn imports for

[7] National Research Council, Committee on Economic and Environmental Impacts of Increasing Biofuels Production, Renewable Fuel Standard: Ptential Economic and Environmental Effects of U.S. Biofuel Policy (2011), http://books.nap.edu/catalog.php?record_id=13105.

developing countries. In Guatemala, the additional expense (28 million dollars) in 2011 effectively cancelled out all U.S. food aid and agricultural assistance for that year, according to the international anti-hunger group ActionAid.

Additionally, cropland acreage in the U.S. has been declining as it has in all developed countries. According to the USDA's National Agriculture Statistics Service report the number of U.S. farms in 2012 was estimated at 2.2 million, down 11,630 farms from 2011.   The total land in farms, at 914 million acres, decreased 3 million acres from 2011.

However, experts say that the RFS is drawing more farm acreage into corn. According to USDA's recently released March 29, 2013, Prospective Planting report, corn accounts for 97.3 million acres. If realized, 97.3 million would be the most corn planted by U.S. farmers since 1936. By mandating the use of corn, soybeans and other food commodities used to create mandated ethanol and biodiesel, for non-food purposes, the RFS distorts the U.S. and global market for these commodities. Too much corn (and soybeans and other biofuel sources) is planted compared to an efficient market, too little corn substitutes are planted, too much corn is devoted to fuel production, and too little corn is devoted to food use.

Thank you for the opportunity to provide these comments. For additional information or perspectives, please contact AFFI Vice President of Government Affairs Kristin Pearson Wilcox at kwilcox@affi.com or at (703) 821-0770.

Robert L. Greco, III
Group Director: Downstream and Industry Operations

1220 L Street, NW
Washington, DC 20005-4070
USA
Telephone 202-682-8167
Fax 202-682-8051
Email greco@api.org
www.api.org

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The Honorable Fred Upton	The Honorable Henry Waxman
Chairman	Ranking Member
Committee on Energy and Commerce	Committee on Energy and Commerce
House of Representatives	House of Representatives
2125 Rayburn House Office Building	2125 Rayburn House Office Building
Washington, DC 20515	Washington, DC 20515

Dear Chairman Upton and Ranking Member Waxman,

API appreciates the opportunity to respond to your questions in the Committee on Energy and Commerce white-paper examining impacts of the RFS on the agricultural sector, RFS waiver, and cellulosic biofuels issues.

The Clean Air Act's supposed flexibility to address issues with the implementation of the RFS hinges on EPA's willingness to modify the requirements. In theory, Section 211(o)(7) of the Clean Air Act ("Waivers") provides EPA with flexibility to address the unintended, adverse effects of the RFS on the U.S. economy and consumers. In reality, however, EPA has repeatedly exhibited a reluctance to modify the RFS requirements and use these "waivers" to alleviate the burdens of the RFS, thereby eviscerating any supposed statutory flexibility to address the problems with the RFS.

Pursuant to Section 211(o)(7)(A) of the Clean Air Act, EPA may waive the requirements of the Renewable Fuels Standard (RFS) if (i) "implementation of the [RFS] would severely harm the economy of a State, region, or the United States," or (ii) "there is an inadequate domestic supply." In 2012, the governors of Arkansas, Delaware, Georgia, Maryland, New Mexico, North Carolina, Texas, and Virginia petitioned EPA to waive some portion of the RFS because of the severe economic harm that the RFS caused while the drought of 2012 plagued a significant portion of the country. On November 16, 2012, EPA denied those waiver requests. There are many lessons that can be learned from the waiver denial.

As a threshold point, even though API remained neutral on whether EPA should grant the waiver in 2012, we submit that if EPA did not believe that the most severe drought in the United State since the 1950s failed to merit a suspension of the RFS, then there may never be a situation when impacts on the food and livestock industries would successfully receive a waiver from EPA. The agency's refusal to grant a waiver can be, at the very least, attributed to its unnecessarily high standard for granting a waiver. If EPA were to follow the letter of the law – instead of self-imposed, nearly insurmountable hurdles – the agency might be more likely to grant a waiver of the RFS requirements.

In its decision to deny the waiver requests, EPA stated that any waiver petition must show – with "a generally high degree of confidence" – that the implementation of the RFS *alone* must cause severe economic harm. In addition, EPA demanded "a high threshold for the nature and degree of harm." Even if a waiver petition were to satisfy EPA's severe harm test, the agency also stated that it might still decline to issue a waiver. EPA's approach would seem to eliminate any chance of fixing a RFS problem before the damage has begun. These unnecessarily high hurdles and foreshadowing of future denials – even if those hurdles are cleared – demonstrate that the current RFS is flawed and needs to be repealed. API believes that EPA has broader authority to grant waivers. Indeed, Section 211(o)(7)(A) of the Clean Air Act permits EPA to grant a waiver if a petitioner demonstrates that the RFS will likely contribute to severe economic harm. Since EPA's 2012 waiver decision, the facts are significantly different now that the E10 blend wall has been reached. The issuance of a waiver could alleviate some of the harmful effects of the blend wall. A recent study by NERA[2] shows that continued implementation of the RFS without addressing the blend wall could cause severe economic harm.

EPA's rigidness goes well beyond the refusal to grant waivers for severe economic harm. Indeed, it extends to the approach that EPA has taken with regards to the cellulosic biofuel requirement and reducing the burden of the RFS as a whole. Following decades of research and "technology forcing" legislation (i.e. RFS1, RFS2 and California's Low Carbon Fuel Standard), cellulosic biofuels have failed to become available at a commercial scale that is economically competitive in the existing U.S. transportation fuels market. For the period 2010 to 2013, a total volume of 1.85 billion gallons of cellulosic biofuel has been mandated by RFS2. Production has utterly failed to live up to the mandate.

Because the cellulosic biofuel industry has failed to produce commercial volumes, EPA has needed to lower the statutory cellulosic biofuel volumetric requirements each year. When EPA lowers the cellulosic biofuel requirement from the statutory mandate to the "projected" amount,[1] the agency has the statutory authority to "reduce the applicable volume of renewable fuel and advanced biofuels" by that same quantity as well, pursuant to Section 211(o)(7)(D)(i). EPA does not need to conduct a special rulemaking for this waiver; indeed, the agency may consider this waiver as part of its yearly process in setting the RFS mandates. Despite this basic waiver authority, however, EPA has refused to exercise its discretion and reduce these other RFS requirements.

For example, in its proposed 2013 RFS, EPA reduced the statutory mandate of 1 billion gallons to 14 million ethanol equivalent gallons. Accordingly, EPA can lower the advanced and total renewable fuel RFS requirements each by 986 million gallons. This simple volumetric reduction would lower the ethanol requirement from roughly 10.9% to 10.2% of the 2013 annual gasoline demand anticipated by EIA. While still above the E10 blendwall, this reduction could potentially alleviate much of the current volatility in the secondary RINs market that may be reacting to the anticipated RIN shortage associated

[1] API has successfully challenged EPA's "projected" volumes for cellulosic biofuel in the 2011 and 2012 RFS. It remains to be seen what EPA will require for 2013, even though we are almost through 4 months of the year.

with the blendwall.[2] To date, however, EPA has failed to take advantage of the flexibility that congress intended the agency to use for these very situations.

Cellulosic biofuels have not only failed to live up to expectations, but they have also failed to succeed in diversifying the RFS. This trend is expected to continue through 2015, as capacity is projected to be only a small fraction of the 2015 mandate of 3 billion gallons.[3] Furthermore, EIA in its 2013 Annual Energy Outlook projects less than 500 million gallons of cellulosic biofuels (ethanol and diesel) in 2022 vs. 16 billion gallons mandated by RFS2. To date, the U.S. EPA has waived, or has proposed to waive, over 98% of the cellulosic biofuel mandate, and large waivers will likely continue to be necessary. Based on findings of the National Academy of Sciences report,[4] cellulosic biofuel volumes mandated by the RFS2 are unlikely to be met, unless there is a major technological innovation or policy change. As noted above, however, EPA has not used its discretionary authority to waive the total renewable fuel mandate. This has the direct negative consequence of increasing the reliance on food-based crops. When the cellulosic biofuel mandate has been waived, the resultant gap has been filled mainly by increased volumes of both sugar-cane based ethanol and biomass-based diesel derived from oil seed (food) because EPA has chosen not to waive the total renewable fuel mandate. If this trend continues as the statutory cellulosic biofuel mandate becomes greater, then greater imports of advanced biofuels – mainly sugar-cane based ethanol – will likely be required to fill the gap, especially in the short term. As EPA has itself observed in the 2013 RFS proposal, there are questions as to whether the production capacity of Brazil, historically the primary supplier of US sugar cane ethanol imports, is sufficient for this purpose. The intent of the "cap" on both corn ethanol and biomass-based diesel was in part to protect the food supply from becoming the sole provider of the 36 billion gallons of biofuel. But, if the total renewable fuel mandate is not waived along with the cellulosic biofuel mandate as the cellulosic biofuel mandate grows, the burden of all of the RFS will be placed on food crops.

In addition to the above mentioned National Academy of Sciences report which highlighted, among other issues, negative environmental impacts of biofuels on water, soil, land, air quality, and wildlife habitat, the Congressional Research Service published a recent study with similar concerns about the RFS[5]. The CRS study states: "the biofuels-driven expansion in feedstocks production has heightened competition for available cropland between biofuels and other field crops…" Data in that report show that ethanol uses an increasing share of US corn production (now accounting for about 40% and growing), while corn for feed use has fallen sharply. "Corn prices have trended steadily upward in direct relation to the added growth in demand from the ethanol sector. USDA projects corn prices to remain in the $4 to $5 per bushel range through 2020, compared with an average farm price of $2.15 per bushel during the 10-year period from 1997 to 2006." Furthermore, the study concludes that in order to enable new corn acreage, shifts in crop rotation from soybeans to corn will need to occur and "corn-to-soybean price ratio would have to tilt fairly strongly." Simply put, the RFS contains unfulfilled aspirational goals and numerous unintended consequences including environmental, food and energy

[2] NERA Economic Consulting, "Economic Impacts Resulting from Implementation of RFS2 Program", October, 2012.
[3] E2 Environmental Entrepreneurs, *Advanced Biofuel Market Report 2012*, October 2012.
[4] National Academy of Sciences, "Renewable Fuel Standard Potential Economic and Environmental Effects of U.S. Biofuel Policy", 2011.
[5] Congressional Research Service, "Renewable Fuel Standard (RFS): Overview and Issues" by R. Schnepf and B. Yacobucci, March 2013.

implications. Again, we appreciate the opportunity to provide these responses. If you have any questions, please don't hesitate to contact us.

Sincerely,

Robert L. Greco

Bob Greco
Group Director: Downstream and Industry Operations

API is a national trade association that represents all segments of America's technology-driven oil and natural gas industry. Its more than 500 members – including large integrated companies, exploration and production, refining, marketing, pipeline, and marine businesses, and service and supply firms – provide most of the nation's energy. The industry also supports 9.2 million U.S. jobs and 7.7 percent of the U.S. economy, delivers $86 million a day in revenue to our government, and, since 2000, has invested over $2 trillion in U.S. capital projects to advance all forms of energy, including alternatives.

American Soybean Association®

If you believe, belong.

12125 WOODCREST EXECUTIVE DRIVE, SUITE 100, ST. LOUIS, MO 63141-5009 • PHONE: (314) 576-1770 • FAX: (314) 576-2786

April 29, 2013

The Honorable Fred Upton, Chairman
The Honorable Henry Waxman, Ranking Member
Committee on Energy & Commerce
U.S. House of Representatives

Dear Chairman Upton, Ranking Member Waxman, and Committee Members:

The American Soybean Association (ASA) appreciates the opportunity to comment on the Renewable Fuel Standard Assessment White Paper on Agricultural Sector Impacts developed by the Committee on Energy & Commerce. The ASA is the national, not-for-profit trade association that represents nearly 600,000 United States soybean producers on domestic and international policy issues.

Soybean farmers have played a major role in the development of the U.S. biodiesel industry and biodiesel has provided a significant market opportunity for U.S. soybean producers. However, first and foremost, policymakers must understand that markets and prices for soybeans are driven by demand for soy meal as a protein feed source for livestock. The portion of the soybean used in biodiesel production is the oil, not the meal. Soybeans consist of 80% meal and only 20% oil. Because demand is driven by the meal markets, soy oil has traditionally existed in surplus and biodiesel provides an important market outlet to utilize surplus soy oil.

Additionally, in considering the use of soybean oil for biodiesel production, it must be understood that demand for U.S. soybean oil for food use began to decline significantly following the U.S. Food and Drug Administration's (FDA) action in 2003 to require food manufacturers to include trans fats on nutrition labels beginning in 2006.[1] The increase in the use of soybean oil for the biodiesel market has essentially taken up the reduced demand for soybean oil in the food sector associated with trans fat labeling as the food industry shifted away from the use of partially hydrogentated soybean oil to various oil blends and the increased use of palm oil.

Finally, while soybean oil initially was the predominate feedstock used to make biodiesel, as the amount of biodiesel produced in the U.S. has increased, the share of that market for soybean oil has decreased to approximately 50-55% in 2012. The remaining share of the U.S. biodiesel feedstock market has been met from other feedstocks such as canola oil, corn oil extracted from distillers grains from ethanol production, animal fats, and used cooking oil.

[1] Trans fats are produced when liquid vegetable oils are partially hydrogenated to make them more stable for certain baking or frying operations.

These soybean market fundamentals are essential to the understanding of the impact of the Renewable Fuel Standard (RFS) on soybeans. While there has been an increase in soybean prices that has coincided with the increase in the RFS, the increased demand for soybeans and soy meal started well before the RFS and is mostly attributable to increased demand from China and record levels of soy exports over the same timeframe. Over half (56-58%) of the U.S. soybean crop is exported and more than one quarter of the entire U.S. crop, half of our total exports, goes to China. The increasing population in China and other developing countries in the world, and the rising incomes of this population that enables them to incorporate more meat and fish protein in their diet, is by far the leading demand factor for U.S. soybeans. Recalling once again that soybeans are 80% protein/20% oil, it is the 80% protein fraction of the soybean that is used domestically and worldwide to make high protein feed that is a necessary ingredient for the production of pork, poultry, milk, beef, and aquaculture products. As the Chinese and world populations have increased and incomes have risen, the first area where people spend their increased incomes is to improve their diets. This drives demand for increased meat, poultry, egg, and aquaculture production, which in turn drives demand for soybean production and use. These factors are illustrated in Tables 1, 2, 3, and 4 below.

Table 1
Soybean Imports by China and Rest of World

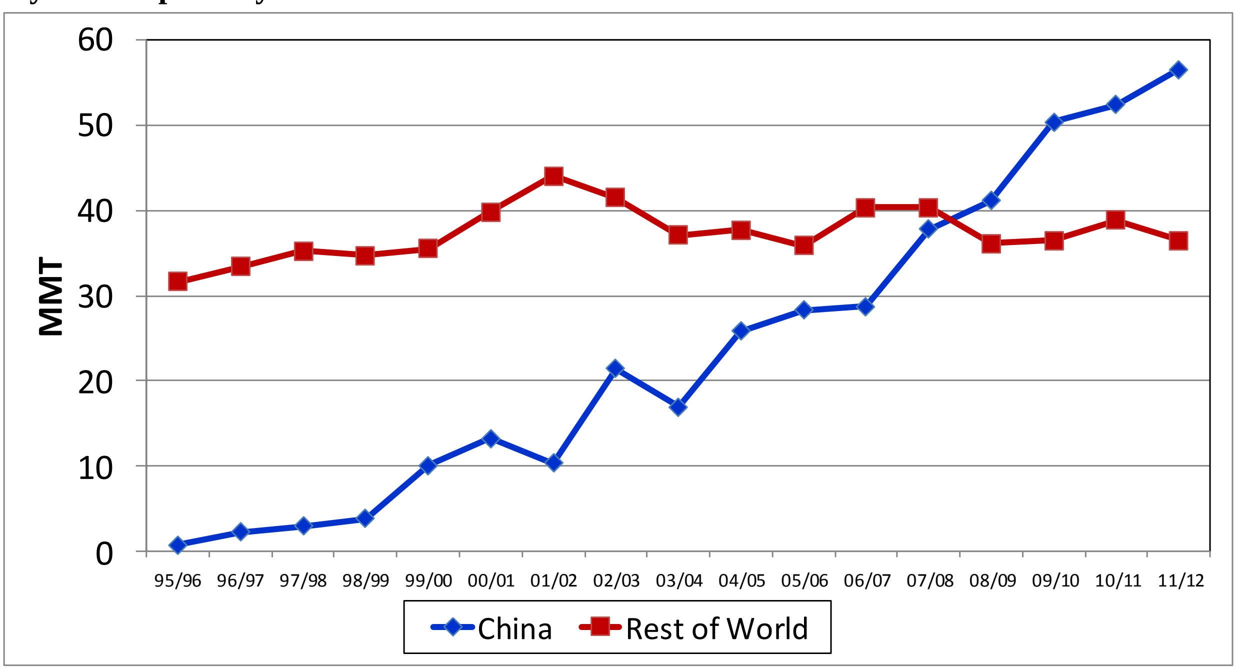


Table 2
China's Soymeal Consumption

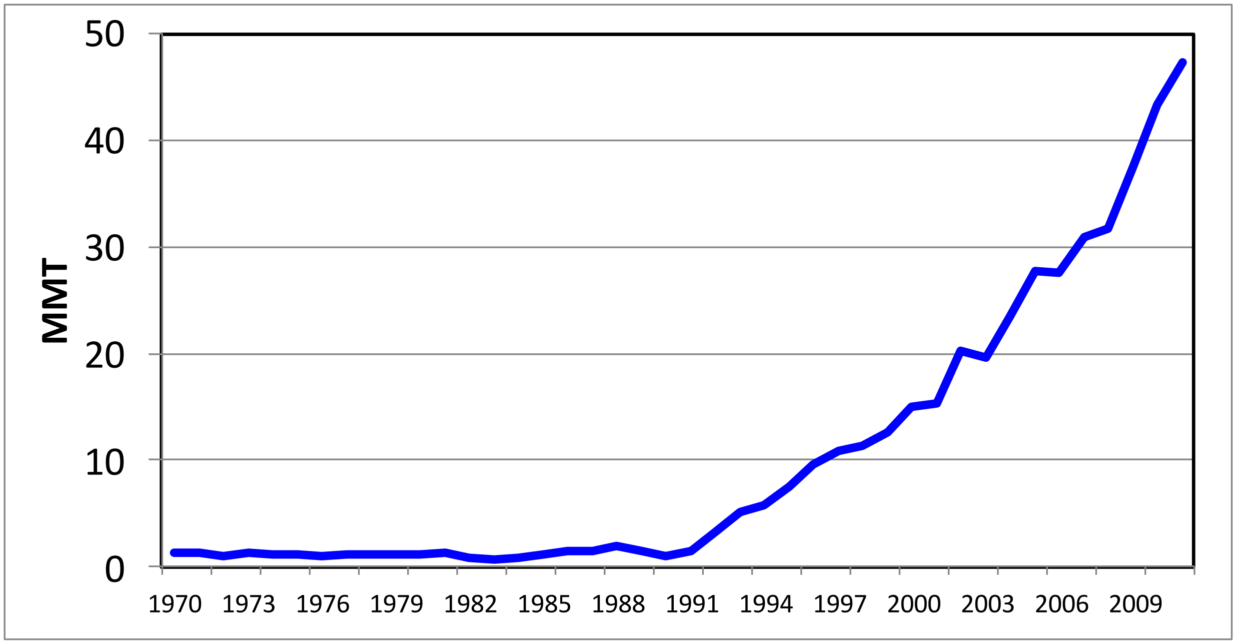


Table 3
China's Annual Per Capita Consumption of Meat, Excluding Fish

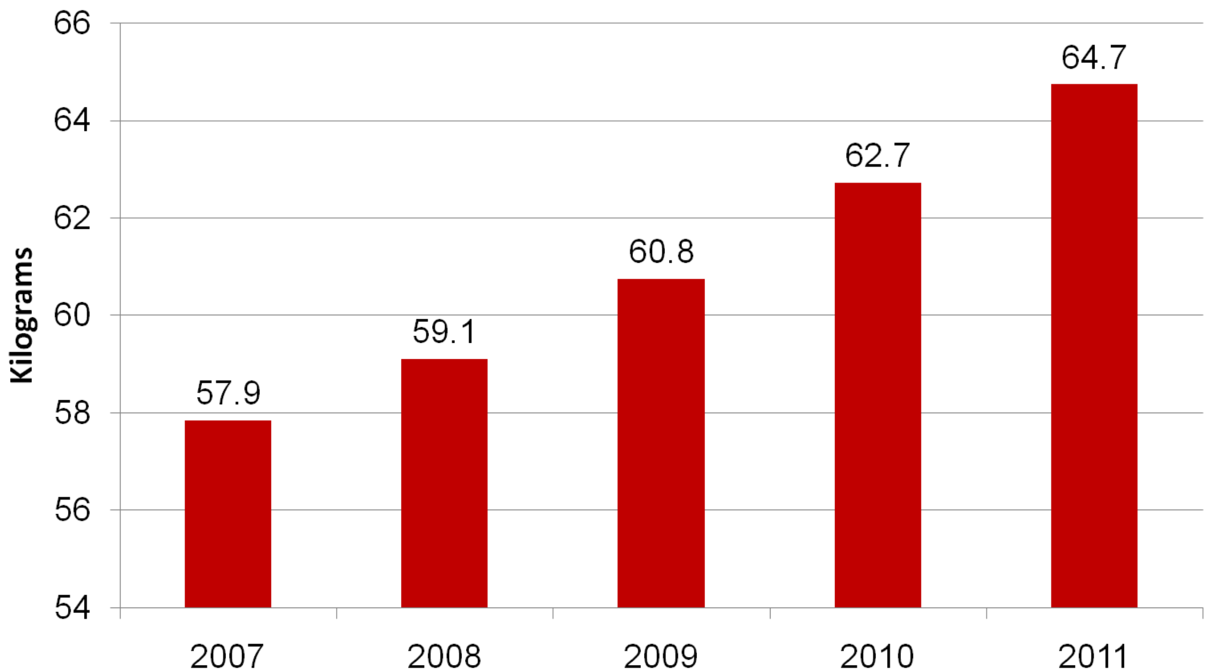


Table 4
U.S. Soybean Exports (Million Metric Tons)

Country	2006/07	2007/08	2008/09	2009/10	2010/11
China	11,090,697	13,693,778	18,522,698	22,396,126	24,353,669
Total U.S. Exports	30,386,049	31,538,170	34,816,678	40,797,456	40,797,456

As you can see from Table 4 above, from 2006/7 through 2010/11, total exports of U.S. soybeans have increased from 30.3 million metric tons (MMT) to 40.8 MMT. In that time, exports to China have more than doubled, going from 11 MMT to 24.3 MMT.

Following are responses to the specific questions posed in the committee's white paper:

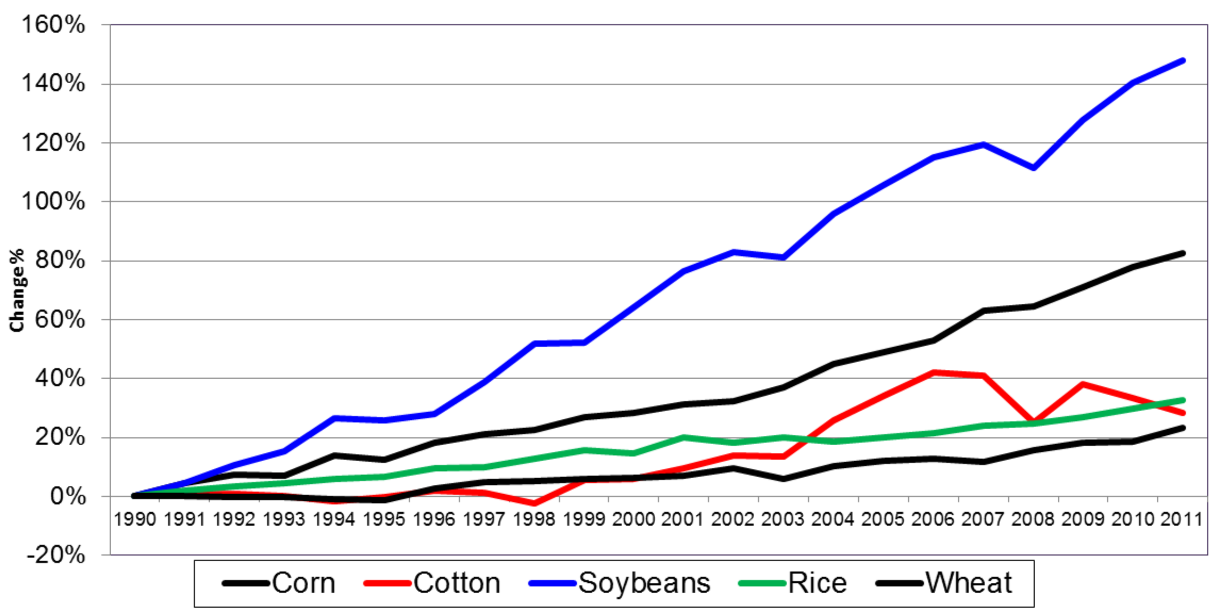
Questions for Stakeholder Comment

1. **What has been the impact of the RFS on corn prices in recent years? What has been the impact on soybean prices? Have other agricultural commodity prices also been affected?**

The impact of the RFS on soybean prices in recent years has been positive for both soybean farmers and many of our customers. The biodiesel market has provided an outlet for soy oil that would otherwise exist in surplus, including that which has been displaced from food markets as a result of the trans fat issues. As a result, biodiesel has prevented soy oil prices from dropping. In 2009 the United Soybean Board commissioned a "Return on Investment" (ROI) study on biodiesel that assessed the financial impact on soybean farmers. According to the study, from 2005 through 2009, the biodiesel industry's demand for soybean oil supported U.S. soybean prices by 9-27¢ per bushel.

However, while biodiesel has resulted in increased soybean prices, it is important to understand its impact relative to other factors. Table 5 below shows the increase in global consumption of soybeans, corn, wheat, rice, and cotton since 1990. As you can see, consumption was increasing, especially for soybeans, well before there was any significant production of biodiesel or biofuels.

Table 5
Percentage Change in Global Consumption



From 2001/2 through 2007/8, soybean prices increased from $4.38 per bushel to $10.10 per bushel. From 2007/8 through 2011/12, soybean prices increased further to $12.50.[2] The 9-27 cent per bushel increase attributable to biodiesel demand is only a small portion of the increased soybean prices. The largest factor impacting soybean prices has been the increased global consumption, particularly from China. Exports of U.S. soybeans have increased approximately 35% since 2006/7 with exports to China more than doubling during that time.

On the customer side, to the extent that biodiesel demand has provided a market for soy oil, that has enabled and encouraged soybean production resulting in increased supplies of soy meal than otherwise would have existed. This increased meal supply results in lower meal prices for livestock feed. This dynamic has been quantified in an analysis conducted by Centrec Consulting Group, LLC in 2011, which demonstrated how biodiesel demand has resulted in meal prices being $16 to $48 per ton lower than they would have otherwise been from 2005 through 2009.[3] Most livestock producers recognize that the use of soybean oil for biodiesel production has been a net positive for them in that it not only has resulted in lower priced soybean meal for feed rations, but also has provided a valuable outlet for animal fats as a biodiesel feedstock.

2. **How much has the RFS increased agricultural output? How many jobs has it created? Have any jobs been lost? What is the net impact on the agriculture sector?**

A recent economic study conducted for the National Biodiesel Board estimates that the biodiesel industry supported more than 60,000 jobs in 2012, generating income of nearly $3.2 billion to be circulated throughout the economy, and supporting nearly $6.1 billion in GDP. The industry's economic impact is poised to grow significantly with continued production increases. The industry supports jobs in a variety of sectors, from manufacturing to transportation, agriculture and service. It is important to note that not all of these jobs are solely attributable to the RFS.

It would be difficult to isolate the impact of the RFS on agricultural output and its net impact on the agriculture sector. However, according to the Income Statement for the U.S. Farm Sector 2009-2013 published by the USDA Economic Research Service, from 2009-2013 – a period in which the RFS and biofuel production has increased - the U.S. farm sector has experienced an increase in cash receipts for both crops and livestock, farm related income, gross cash income, and net cash income. Net farm income during this period has more than doubled. In addition, direct government payments to the farm sector have decreased.[4]

In his testimony on March 5, 2013 at the House Agriculture Committee hearing "To Review the State of the Rural Economy," USDA Secretary Tom Vilsack stated that, "After adjusting for inflation, net farm income is projected to be the highest in four decades, and aggregate farm equity is at an all time high."[5] This has occurred despite a record drought last year and other recent disasters.

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[2] USDA, Economic Research Service, Oil Crops Outlook, p. 8. March 12, 2013. http://www.ers.usda.gov/media/1056538/ocs13c.pdf

[3] Centrec Consulting, Soybean Oil and Meal Economics, February 2011.

[4] USDA, Economic Research Service, Income Statement for the U.S. Farm Sector 2009-2013. February 11, 2013. http://www.ers.usda.gov/data-products/farm-income-and-wealth-statistics.aspx#27377

[5] http://agriculture.house.gov/sites/republicans.agriculture.house.gov/files/pdf/hearings/Vilsack130305.pdf

There are greater factors beyond the RFS that have contributed to this success, but ASA believes that the RFS has had a positive impact on agricultural output, jobs, and a positive net impact on the agriculture sector.

3. **Was EPA correct to deny the 2012 waiver request? Are there any lessons that can be drawn from the waiver denial?**

EPA was correct in not granting a waiver of the biomass-based diesel portion of the RFS in 2012. ASA believes that the RFS provisions governing biomass-based diesel are functioning as intended and a waiver was not warranted or necessary in 2012. The waiver requests did not specifically address biomass-based diesel and did not identify or request relief that can be provided through a waiver nor did the waiver petitions provide evidence to support a waiver of the biomass-based diesel portions of the RFS. ASA believes that EPA's decision not to provide a waiver of the biomass based diesel portion of the RFS has proven correct and one lesson that can be drawn is that the biodiesel industry, even in a drought year, is able to meet the Required Volume Obligations of the RFS without adverse impact.

4. **Does the Clean Air Act provide EPA sufficient flexibility to adequately address any effects that the RFS may have on corn price spikes?**

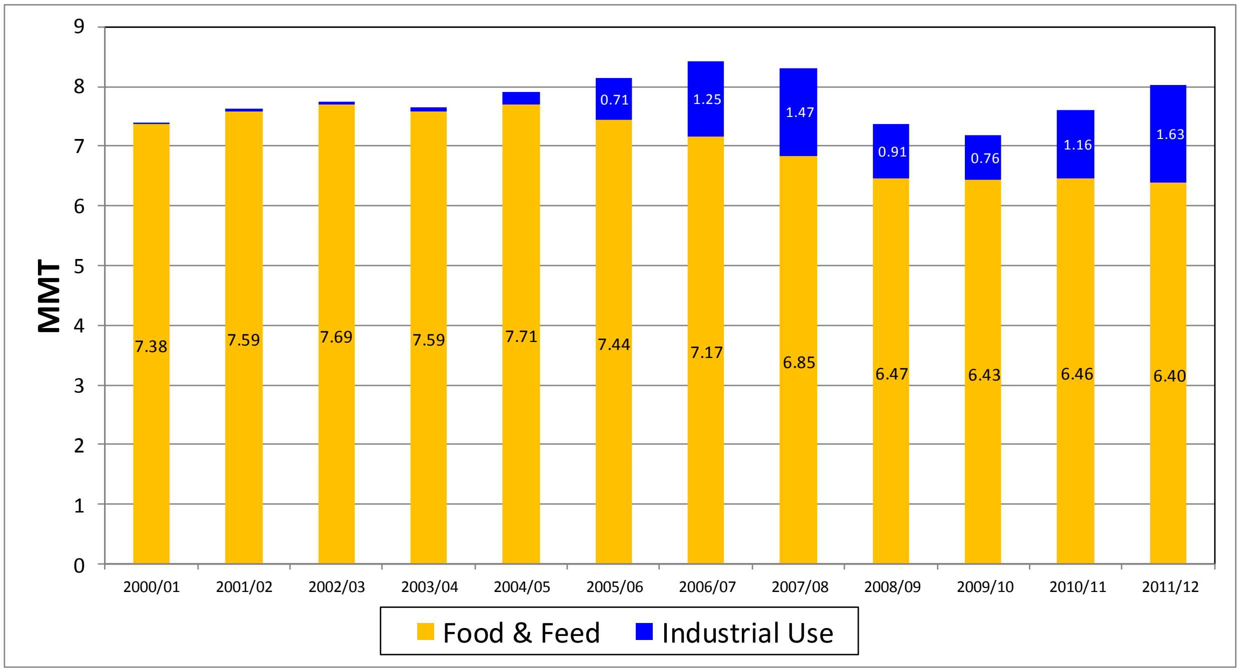
ASA has no position or comment on this question.

5. What has been the impact, if any, of the RFS on food prices?

ASA believes that the RFS, especially the biomass-based diesel portion, has had minimal impact on food prices. In fact, as demonstrated in our comments, biodiesel has a positive impact on meal supplies for the livestock industry, which in turn has positive implications for meat, poultry, and aquaculture supplies to consumers. Processing biodiesel from soybeans uses only the 20% oil portion of the soybean, leaving all of the protein available to nourish livestock and humans. By providing a market for soybean oil, biodiesel increases the availability of protein-rich meal for human and livestock consumption. The increased meal supply results in a more cost-effective food and feed source.

As seen in Table 6, the amount of soybean oil used for biodiesel production or other industrial uses is relatively small. In recent years soy oil has been displaced in food products due to trans fat issues and biodiesel has mostly replaced that lost market.

Table 6
U.S. Soyoil Consumption For Food/Feed and Industrial Use



6. **What role could cellulosic biofuels play in mitigating the potential effects of the RFS on corn prices?**

ASA has no position or comment on this question.

7. **What impact are cellulosic biofuels expected to have on rural economies as the production of such fuels ramps up?**

ASA has no position or comment on this question.

8. **Will the cellulosic biofuels provisions succeed in diversifying the RFS?**

ASA has no position or comment on this question.

9. **What is the scale of the impact of the RFS on international agricultural production and global land use changes?**

Many factors, including world population growth, market economics, urbanization, and dietary changes impact land use changes. The RFS, U.S. biofuels, and biodiesel cannot be singled out for responsibility for land use changes. New cropland is not established to make biodiesel because it is generally produced from co-products of crops already being grown. From 2004 to 2008, when U.S.

biodiesel production climbed from 25 million to 700 million gallons, soybean acres in the U.S. stayed virtually the same and soybean acres in Brazil decreased. Any increase in agricultural production and global land use change would be far more directly correlated with global population increase and increased global protein consumption. It is also important to note that increased yields have and will continue to enable farmers to produce more using less land. Increased market demand results in investments and innovations in technologies and agronomic practices employed by farmers that increase yields.

Indeed, in passing the Energy Independence and Security Act (EISA) of 2007, which expanded the RFS, Congress understood that increased production of biomass-based diesel provided substantial reductions in greenhouse gas (GHG) emissions compared to baseline petroleum and sought to preserve those reductions. The lifecycle analysis conducted by EPA, which takes into account international land use changes, determined that biodiesel meets the required GHG threshold for biomass-based diesel in a range of 57 to 86% when compared to petroleum diesel.

Thank you again for the opportunity to provide input and comment on the Renewable Fuel Standard Assessment White Paper on Agricultural Sector Impacts developed by the Committee. ASA believes that EPA and Congress should continue to support the biomass-based diesel portion of the RFS and not consider waiving, revising or repealing the biomass-based diesel volume requirements as long as the U.S. biodiesel industry continues to demonstrate the ability to meet the existing statutory and regulatory requirements.

We hope the information we have provided is helpful. If you have any questions or would like additional information, please contact Tom Hance at thance@gordley.com or 202-969-7040.

Sincerely,

Danny Murphy

Danny Murphy, President
American Soybean Association

Arkansas Cattlemen's Association
310 Executive Court • Little Rock, Arkansas 72205 • (501) 224-2114 • Fax (501) 224-5377
AFFILIATED WITH NATIONAL CATTLEMEN'S BEEF ASSOCIATION

April 29, 2013

United States House of Representatives
Committee on Energy and Commerce
Chairman Fred Upton
2125 Rayburn House Office Building
Washington, DC 20515

Dear Chairman Upton and the Committee on Energy and Commerce,

RE: Comments on White Paper – Renewable Fuel Standard Assessment, Agricultural Sector Impacts

I am writing in reference to the Renewable Fuel Standard (RFS) Assessment White Paper, in order to share the perspective of Arkansas cattle farmers and the tremendous pressure we have faced as a result of 40% of corn being diverted to ethanol.

As you all pointed out, in 2013 corn has averaged about $7 per bushel, which is over **three** times what it was before the RFS was enacted. This has been detrimental for farmers, who depend on affordable feed to provide food for our families and our nation. I strongly believe that if congress moved to open up the RFS to other feedstocks, such as natural gas, there would be a measurable change in corn prices. In turn, this would stabilize feed prices and relieve the imbalance that has forced the agriculture industry to raise food prices or face insolvency.

We *must* focus on building a broad and comprehensive energy policy that includes new technologies and harnesses existing natural resources. I support ongoing efforts to reform our nation's alternative fuels policy. Specifically, I support the need to update the RFS to allow a broader range of domestic fuel sources to be used to make ethanol.

Here in Arkansas, we saw incredible suffering as a result of the drought last summer. Hard-working, long-time farmers even had to put down cattle in their herd because they couldn't feed them. At the same time, an increasing amount of perfectly good corn went to ethanol. Modifying the RFS would bring both immediate and long-term relief to this disparity. Expanding the conventional biofuels portion of the RFS would lead to many benefits, both nationwide, and here in Arkansas. Benefits include:

1. It ramps up a new alternative fuel industry, creating thousands of jobs and injecting billions of dollars into local economies.
2. Will open more states to ethanol production and reduces the cost of transporting ethanol from corn-growing states
3. Ultimately will lower the price of ethanol, which, in turn, could bring down the price of gasoline. It mitigates the harmful effects of corn ethanol production on the environment. And it reduces our reliance on foreign oil.

In response to your inquiry, “what has been the impact, if any, of the RFS on food prices?” I will tell you that it has had a profoundly **negative** impact and needs to be amended. Only with a true comprehensive energy approach will we grow our fuel economy and gain greater energy independence.

Sincerely,

Adam McClung
Executive Vice President,
Arkansas Cattlemen’s Association

310 Executive Court
Little Rock, AR 72205
(501-224-2114)

April 29, 2013

United States House of Representatives
Committee on Energy and Commerce
Chairman Fred Upton
2125 Rayburn House Office Building
Washington, DC 20515

Dear Chairman Upton and the Committee on Energy and Commerce,

RE: Comments on White Paper – Renewable Fuel Standard Assessment, Agricultural Sector Impacts

I am writing in response to the Renewable Fuel Standard (RFS) Assessment White Paper, in order to share my experience as a dairy farmer, and the tremendous pressure we have faced as a result of 40% of corn being diverted to ethanol.

You reported yourself that in 2013 corn has averaged about $7 per bushel, which is over THREE times what it was before the RFS was enacted, and an unnatural and devastating swing for farmers like me, who depend on affordable feed to provide food for our families and our nation. I strongly believe that if congress moved to open up the RFS to other feedstocks, such as natural gas, there would be a measurable change in corn prices that would stabilize feed prices and relieve the imbalance that has forced the agriculture industry to raise food prices or face insolvency.

In this era of global instability and economic uncertainty, we need to focus on building a broad and comprehensive energy policy that includes new technologies and harnesses existing natural resources. That is why I am in support of efforts to reform our nation's alternative fuels policy – in particular, the need to update the RFS to allow a broader range of domestic fuel sources to be used to make ethanol.

Here in Arkansas, we saw incredible suffering as a result of the drought last summer. Hard working, dedicated farmers had to put down cattle in their herd because they couldn't feed them; meanwhile an increasing amount of perfectly good corn went to ethanol. A modified RFS, which currently leans too heavily on corn, would bring both immediate and long-term relief to this disparity. Expanding the conventional biofuels portion of the RFS imparts many benefits both nationally and locally. Impacts include:

1. It ramps up a new alternative fuel industry, creating thousands of jobs and injecting billions of dollars into local economies.
2. Will open more states to ethanol production and reduces the cost of transporting ethanol from corn-growing states
3. Ultimately will lower the price of ethanol, which, in turn, could bring down the price of gasoline. It mitigates the harmful effects of corn ethanol production on the environment. And it reduces our reliance on foreign oil.

So, in response to your inquiry, "what has been the impact, if any, of the RFS on food prices?" I am here to share my on-the-ground perspective and tell you that it has had a profoundly negative impact and needs to be amended. Only with a true "all of the above" energy approach will we grow our fuel economy and gain greater energy independence.

Sincerely,

Floyd Wiedower

Floyd Wiedower

Director, Arkansas Dairy Cooperative Association

April 29, 2013

The Honorable Fred Upton
House Energy & Commerce Committee
2125 Rayburn House Office Building
Washington, DC 20515

The Honorable Henry Waxman
House Energy & Commerce Committee
2322A Rayburn House Office Building
Washington, DC 20515

Dear Chairman Upton and Ranking Member Waxman:

The Association of Equipment Manufacturers (AEM) appreciates the opportunity to comment on the Energy & Commerce Committee's request for information on the Renewable Fuel Standard's (RFS') impact on the economy of rural America and agriculture.

AEM is the U.S.-based international trade group serving the off-road equipment manufacturing industry. AEM members number more than 850 companies that manufacture equipment, products and services used worldwide in the agriculture, construction, forestry, mining and utility fields. Our agricultural equipment manufacturing members are an integral part of the agricultural economy and are committed to encouraging a robust renewable fuels industry.

RFS' Positive Impacts on the U.S. Equipment Manufacturing Industry and Rural America

The RFS is providing the market stability necessary to attract scarce investment capital for the continued development of the renewable fuels industry. Tampering with the RFS now would be a huge blow to the industry as it would create uncertainty, thereby scaring away investors. This in turn would slow the development of the next generation of renewable fuels that do not rely on foodstuffs, namely cellulosic ethanol made from field residue such as corn cobs. Agricultural equipment manufacturers have invested considerable resources in the research and development of products specifically designed to collect the biomass necessary to produce cellulosic ethanol on a grand scale. With several commercial-scale cellulosic ethanol plants currently under construction, this new market for equipment is fast approaching and in some cases is already here.

Threatened market instability could further spill over into the established agricultural equipment sector endangering current jobs. Based upon a 2008 economic study conducted by IHS Global Insight, 250,000 American jobs are directly and indirectly supported by the agricultural equipment sector. The RFS has played an important role in helping to ensure strong demand and growth in this important manufacturing sector. A weakened RFS would serve as a drag on future growth in the agricultural equipment manufacturing industry and the rural communities that depend upon it.

For decades, the economic condition of rural America has been in steady decline as young adults migrated to urban areas for education and employment opportunities. How to solve this problem has been the focus of much attention, and the renewable fuels industry has shown itself to be a critical part of the solution. A 2012 economic study performed for the Renewable Fuels Association shows this sector supported 90,200 direct jobs and 311,400 indirect jobs in 2011. Those jobs were spread across the country, with many of them located in rural areas. And according to the Nebraska Public Power District, the average ethanol plant has the following economic impact on a rural community: $100 million in capital construction investment; a boost of more than $70 million to the local economy during construction; expansion of the local economic bases by another $70 million per year; approximately 35 new direct full-time jobs and another 80-90 additional jobs in the area; increased household income of $7 million annually; and millions of dollars in increased local, state and federal tax revenues. These figures show the economic-stimulating power of the RFS in rural America.

RFS' True Impact on Food Prices is Insignificant

Too often the falsely named Food vs. Fuel debate treats the choices presented as a zero-sum game. This is not the actual case. One-third of corn used in ethanol production goes directly back into the food chain in the form of nutrient-dense distillers grains. As either Dried Distillers Grains with Solubles (DDGS) or as Wet Distillers Grains (WDG), this animal feed saves animal producers money. Industry estimates put distillers grains savings at 25 percent compared to corn used as feed.

The only part of the corn kernel removed in ethanol production is the starch, leaving the proteins, oils and fiber behind as feed. Today, distillers grains are a major source of feed in the United States and exported to other counties to be used as animal feed. Additionally, increased production of biodiesel from soybean oil has facilitated growth in soybean meal production in recent years. Soybean meal, a co-product of soybean oil, is a valuable source of protein for livestock and poultry worldwide.

And according to a 2012 study conducted by Cardno-ENTRIX, a reduction in biofuel output might result in nothing more than a trivial corn price reduction, and that small reduction in the price of corn would be partially or fully erased by a resulting increase in the prices for other feed ingredients such as distillers grains (DDGS) and soybean meal.

Fact is, the DDSs have become a critical component of animal agriculture and play an important role in preventing any undue rise in food costs because of the production of renewable fuels.

There are other factors we must discuss when determining the RFS' impact on food prices. The price of commodities, such as corn, accounts for only a small fraction of the final retail cost consumers pay at the grocery. The classic example being a $4 box of Corn Flakes containing less than a dime's worth of corn is quite true. A far more important determining factor in retail food costs is the price of energy, namely transportation fuels, which the RFS helps to lower.

Advancements in technology, increased efficiency, and high crude oil prices make ethanol cheaper to produce than gasoline. In 2008, The DOE stated that without ethanol Americans would be paying 20 to 35 cents more per gallon of gas. Also in 2008, researchers at Iowa State University found that without current ethanol production gasoline would be 29 to 40 cents per gallon higher.

Since that time the production of ethanol has seen significant increases resulting in even greater savings. A 2012 study by Michigan State University looked at the impact of ethanol on gas prices in 2010. Their results determined that, depending on the region of the country, ethanol lowered gas prices .58 cents to $1.37.

Without the RFS consumers would be paying more for food because it would simply cost more to transport inputs along the chain of production all the way to the store shelf.
Not to mention that Americans would be paying even more to drive to the store.

Lastly, to fully understand the RFS' true impact on corn prices we must ask ourselves, what would happen if the RFS simply went away? A 2012 analysis by the Food and Agriculture Policy Research Institute determined that even a full waiver of the RFS' conventional biofuel requirement might reduce corn prices by just 0.5% (4¢/bu.) in 2012-2013.

Conclusion

Based upon all the evidence cited in this letter we applauded the Environmental Protection Agency's denial of the waiver request last year and urge your Committee to continue to support the RFS.

We appreciate the opportunity to submit these comments and if you should have additional questions please contact Nick Tindall, AEM's Director of Government Affairs at ntindall@aem.org or 202-898-9067.

Sincerely,

Nick Yaksich
Vice President
Government & Industry Relations

The Honorable Fred Upton
Chairman
House Energy and Commerce Committee
2125 Rayburn House Office Building
Washington, DC 20515

The Honorable Henry Waxman
Ranking Member
House Energy and Commerce Committee
2322A Rayburn House Office Building
Washington, DC 20515

April 29, 2013

Dear Chairman Upton and Ranking Member Waxman:

Today, the U.S. is the top global consumer of oil, using almost 20 million barrels a day[1]. Our nation's continued reliance on oil ensures not only that the U.S. transportation sector will remain greenhouse gas intensive, but also that American families and our economy will continue to be burdened by the high and volatile prices of the global oil market in addition to the national security challenges that come with oil dependence.

EPA reports that the greenhouse gas emissions attributed to transportation accounted for about 31 percent of U.S. CO2 emissions from fossil fuel combustion in 2011[2], with nearly 65 percent of those emissions stemming from gasoline consumption for personal vehicle use. We simply cannot address climate change if we do not reduce our consumption of oil regardless of whether that oil comes from inside or outside of our nation's borders.

Regardless of how much oil we drill at home, the price that American families pay at the pump and the cost of transportation fuel throughout our economy is dictated by global markets that are manipulated by foreign nations and external forces like OPEC. The International Energy Agency reported in its World Energy Outlook that oil prices will continue to rise in the coming years, reaching $125/barrel (in year-2011 dollars) by 2035 (over $215/barrel in nominal terms)[3]. And, on April 17th, 2013, the International Energy Agency (IEA) released their Tracking Clean Energy Progress report, calling for a more than doubling of renewable fuel production and a sixfold increase in advanced biofuel capacity by 2020 in order to avoid a 2°C rise in global temperatures[4].

The good news is that a national policy is already in place to steadily reduce our dependence on oil. All Congress needs to do is stay the course. In 2007, President Bush signed into law a 15-year roadmap designed to drive investment in renewable fuel and bring new products to market – the Renewable Fuel Standard (RFS). The regulations implementing the RFS weren't even complete until 2010, and yet renewable fuel has already displaced petroleum in 10 percent of our gasoline supply, with 13 billion gallons in 2012[5]. That production supported jobs for, and employed, almost 365,000 Americans[6], while reducing the need for imported oil by more than 462 million barrels[7]. In 2012, using renewable fuel slashed greenhouse gas emissions by 33.4 million metric tons[8]. In 2011, gas prices were reduced by $1.09 per gallon[9] and the average American household saved $1200 on their gas bill thanks to renewable fuel[10].

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[1] http://www.eia.gov/forecasts/steo/report/us_oil.cfm
[2] http://www.epa.gov/climatechange/ghgemissions/gases/co2.html
[3] http://www.iea.org/publications/freepublications/publication/English.pdf
[4] http://www.iea.org/publications/TCEP_web.pdf, page 13
[5] http://ethanolrfa.org/page/-/PDFs/2013%20RFA%20Outlook.pdf?nocdn=1
[6] http://ethanolrfa.org/page/-/PDFs/2013%20RFA%20Outlook.pdf?nocdn=1
[7] http://ethanolrfa.3cdn.net/493f1765e89ddf3319_lkm6i99zf.pdf
[8] http://ethanolrfa.org/page/-/PDFs/2013%20RFA%20Outlook.pdf?nocdn=1
[9] http://www.card.iastate.edu/publications/dbs/pdffiles/12wp528.pdf
[10] http://ethanolrfa.org/page/-/PDFs/2013%20RFA%20Outlook.pdf?nocdn=1

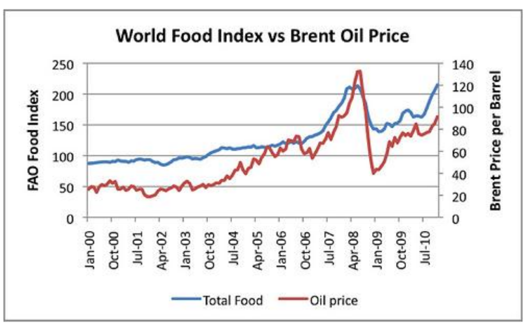
If left intact, the RFS can do even more to reduce oil in our transportation fuel supply and bring increasingly low carbon alternatives to market. The RFS sets forth ambitious targets through 2022 for the production of cellulosic and advanced renewable fuel that meet specific minimum thresholds of lifecycle greenhouse gas emissions reductions reaching 60 percent, depending on the type of fuel. Destabilization of the policy environment will only reduce the pace of commercialization of these new fuels. Just one-third of the way through the 15 year policy, and just three years from the issuance of final regulations, is hardly the time for a re-examination of the policy. This approach is exactly the type of legislative interference in a stable policy environment that undercuts investment and hampers progress and innovation.

All across the United States, farmers are growing more using less land. In 1980, farmers averaged a yield of 91 bushels of corn per acre and produced a crop of 6.6 billion bushels. In 2009, just a generation later, farmers produced an average yield of 164.7 bushels per acre and harvested 13.1 billion bushels. This doubling of the American corn crop was achieved by planting just 3% more corn acres in 2009 than was planted in 1980.[11]

Additionally, **one-third of every bushel of grain processed into ethanol is enhanced and returned to the animal feed market** in the form of distillers grains, corn gluten feed or corn gluten meal, a high-protein, high value and highly nutritious animal feed.[12] This means that the very same corn used for ethanol is also used for animal feed. When this diversion of valuable material to the livestock feed supply is considered, **ethanol production uses well below the erroneous "40% of the corn crop"** cited in your letter. **When this reality is considered, only 3% of the global grain crop goes toward ethanol.[13]**

Given these statistics, it is not surprising that **the price of food is not driven by farm products like corn or by ethanol production.** According to the United States Department of Agriculture's Economic Research Service, 84% of retail food costs are derived from non-farm costs, leaving the cost of food that derives from the value of farm products at 16%[14]. In other words, 16% of the dollar that someone spends at the grocery store goes to pay for the farm products that made the food they're buying, like corn, while the rest goes to things like energy, labor, marketing, packaging and transportation.

The price of food is driven by the price of oil – in fact, since 2000, the two have correlated almost perfectly.



In 2012, the EPA completed an analysis of a request to waive the RFS in response to drought conditions. EPA concluded the following:

[11] http://www.ethanolrfa.org/news/entry/more-ethanol-fewer-resources-increasing-benefits-more-corn-on-fewer-acres-l/
[12] http://www.ksgrains.com/ethanol/ddgs.html
[13] http://www.ethanolrfa.org/pages/ethanol-facts-agriculture
[14] http://www.ers.usda.gov/media/131100/err114.pdf

"EPA's analysis shows that it is highly unlikely that waiving the RFS volume requirements will have a significant impact on ethanol production or use in the relevant time frame that a waiver could apply (the 2012-2013 corn marketing season) and therefore little or no impact on corn, food, or fuel prices.

We analyzed 500 scenarios, and in 89% of them we see no impacts from the RFS program at all. *Looking across all 500 scenarios, including those 11% of scenarios where RFS requirements would have an impact on the corn and other markets, the average impact on corn prices is only 7 cents a bushel, less than a one percent change in corn prices[15]."*

The reality is that **the RFS does not control the price of corn - EPA made the right decision.** Drought harms all agriculture producers, regardless of commodity or sector – this harm is not attributable to the RFS.

The **future growth in the sector lies in the cellulosic and advanced spaces** where billions of dollars have been invested in research and development, testing, and commercialization of an entire industry that did not exist in 2007. Today, the industry is putting steel in the ground on multiple commercial facilities led by companies including INEOS Bio in Vero Beach, Florida; KiOR in Columbus, Mississippi; Abengoa in Hugoton, Kansas; POET-DSM in Emmetsburg, Iowa; and DuPont in Nevada, Iowa. The facilities use a diverse group of feedstocks including municipal solid waste, woody biomass, and corn stover, demonstrating that **the RFS is driving diversity** in feedstock selection.

Rural America will continue to produce the renewable feedstock driving the advanced renewable fuel sector. Some of these facilities described above will co-locate with corn ethanol refineries. From the same corn harvest on the same plot of land that produces corn used for ethanol and DDGs, these facilities will use corn cobs, husks, leaves, and other parts of the harvest that would otherwise be discarded to produce cellulosic renewable fuel. This technology offers the ability to **rapidly scale up the production of cellulosic fuel** and achieve the greenhouse gas emission reductions in the RFS, **without increasing the footprint of agriculture production.** In addition, **farmers have identified the opportunity of the RFS and are diversifying production** around the country with crops like camelina, a feedstock fueling high performance military aircraft, and sorghum, with a recently-approved pathway for biofuel production.

The statute was well-designed to anticipate shifting conditions, providing ample flexibility to deal with any issue that arises. It includes multiple provisions offering flexibility related to the adjustment of targets and timetables in response to anticipated production of renewable fuel as well as annual changes in national gasoline and diesel demand, and compliance flexibility.

The Renewable Fuel Standard ensures that our nation will continue down the path of reducing our dependence on oil, produced at home or abroad, cutting greenhouse gas emissions and breaking the stranglehold that the global oil market has on the price that American families and businesses pay at the pump. It is only with the stability of the RFS that we can continue on our current trajectory to achieve these goals. We cannot afford to go backwards. This well-designed statute is filled with flexibility that, if permitted to function without interference, will stand the test of time and ensure that our goals are achieved. We oppose any modifications to the RFS.

[15] http://www.epa.gov/otaq/fuels/renewablefuels/documents/420f12075.pdf

Bio Biotechnology Industry Organization

ACORE American Council On Renewable Energy

RFA Renewable Fuels Association

aec Advanced Ethanol Council

CFDC Clean Fuels Development Coalition

Archer Daniels Midland Company

Iowa Renewable Fuels Association

DSM Bright Science. Brighter Living.

american coalition for ethanol.

nexsteppe

National Corn Growers Association

novozymes Rethink Tomorrow

DuPont

POET

National Sorghum Producers the voice of the sorghum industry

Abengoa Bioenergy

growth energy America's Ethanol Supporters

25x'25 America's Energy Future

energy future coalition

National Farmers Union United to Grow Family Agriculture

Biotechnology Industry Organization

April 29, 2013

The Honorable Fred Upton
Chairman
Energy and Commerce Committee
U.S. House of Representatives
2125 Rayburn House Office Building
Washington, DC 20515

The Honorable Henry A. Waxman
Ranking Member
Energy and Commerce Committee
U.S. House of Representatives
2322A Rayburn House Office Building
Washington, DC 20515

via email at: rfs@mail.house.gov

Dear Chairman Upton and Ranking Member Waxman:

The Biotechnology Industry Organization (BIO) is pleased to comment on the U.S. House of Representatives Committee on Energy and Commerce's (Committee) second Renewable Fuel Standard (RFS) assessment white paper[1] reviewing the RFS's agricultural sector impacts.

Introduction:

BIO is the world's largest biotechnology organization, with more than 1,100 member companies worldwide. BIO represents leading technology companies in the production of conventional and advanced biofuels and other sustainable solutions to energy and climate change. BIO also represents the leaders in developing new crop technologies for food, feed, fiber, and fuel.

These companies are developing new and innovative ways to help fuel America and the world; providing more environmentally friendly energy crops, cleaner-burning biofuels and renewable chemicals that help reduce greenhouse gas emissions and provide more sustainable sources of energy and materials. These companies are also developing biotechnology crops enabling farmers around the world to produce more abundant harvests on less land with reduced irrigation water, fuel and chemical inputs, and less stress on the environment. Given BIO's broad and diverse set of member companies involved in both energy and agricultural production, we are able to provide a unique perspective on the issues the Committee is seeking to have answered regarding the Agricultural Sector Impacts of the RFS.

As discussed in our response to the Committee's first white paper,[2] the RFS has been a success in driving the commercialization of technologies helping to reduce the U.S. transportation system's overwhelming reliance on foreign petroleum. The RFS provides exactly the type of long-

[1] U.S. House of Representatives Energy and Commerce Committee. 18 Apr. 2013. *RENEWABLE FUEL STANDARD ASSSESSMENT WHITE PAPER: Agricultural Sector Impacts* http://energycommerce.house.gov/sites/republicans.energycommerce.house.gov/files/analysis/20130418RFSWhitePaper2.pdf

[2] Biotechnology Industry Organization. 5 Apr. 2013. *BIO Comments on U.S. House of Representatives Committee on Energy and commerce's White Paper Reviewing the Renewable Fuel Standard (RFS)*. http://www.bio.org/ advocacy/letters/bio-comments-us-house-representatives-committee-energy-and-commerces-white-paper-re

1201 Maryland Avenue SW
Suite 900
Washington DC 20024

202.962.9200 P
202.488.6301 F
bio.org

term regulatory stability needed to send a signal to investors to develop a domestic biofuels industry that lessens our dependence on foreign fuels and creates jobs in America, using homegrown technology.

This will help consumers out not only at the pump, but also at the grocery store, where it has been demonstrated the price of oil has the greatest impact on food inflation – and most other measurers of inflation – according to the U.S. Energy Information Administration.[3] Congress established the RFS to encourage the use of existing biofuels and the development of advanced biofuels in order to reduce our reliance on the rising cost and price volatility of foreign oil. Therefore, it is crucial we maintain the RFS in order to spur on alternative energy production to stabilize and lower both energy and food costs.

White Paper Response:

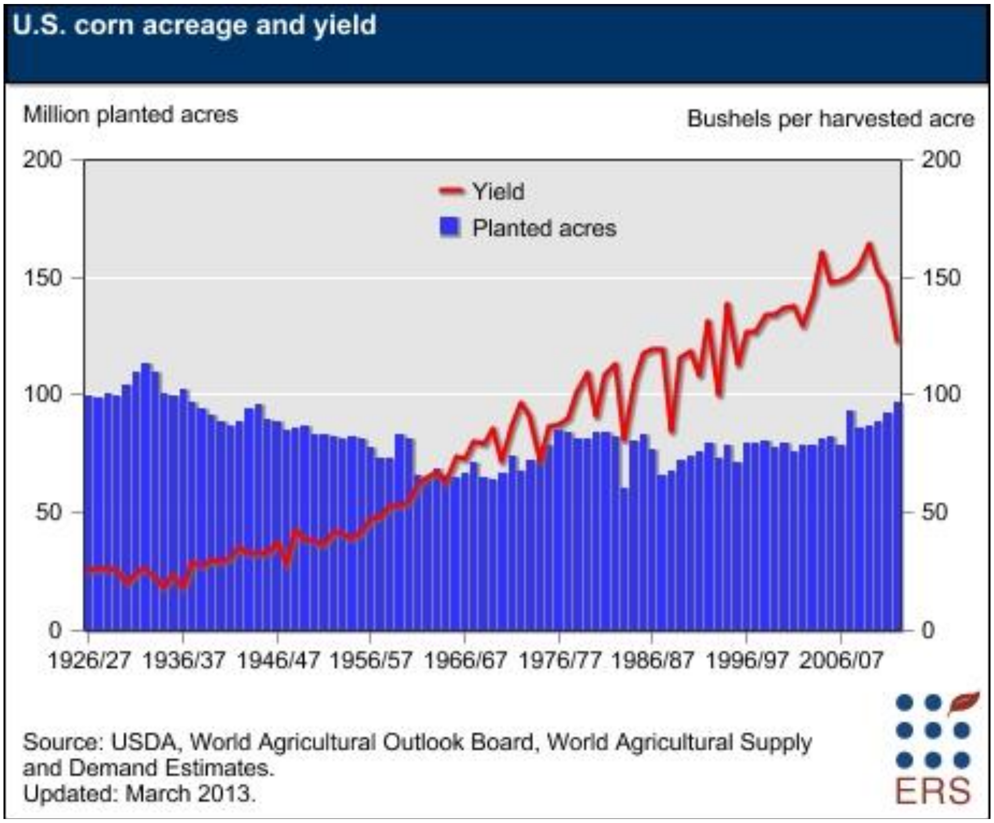
The Committee has again requested comments on a list of questions in this white paper. In order to properly address each question, this paper has each question italicized and listed below. BIO's response will directly follow each question.

Energy and Commerce Committee, RENEWABLE FUEL STANDARD ASSESSMENT WHITE PAPER, Agricultural Sector Impacts, Questions for Stakeholder Comment

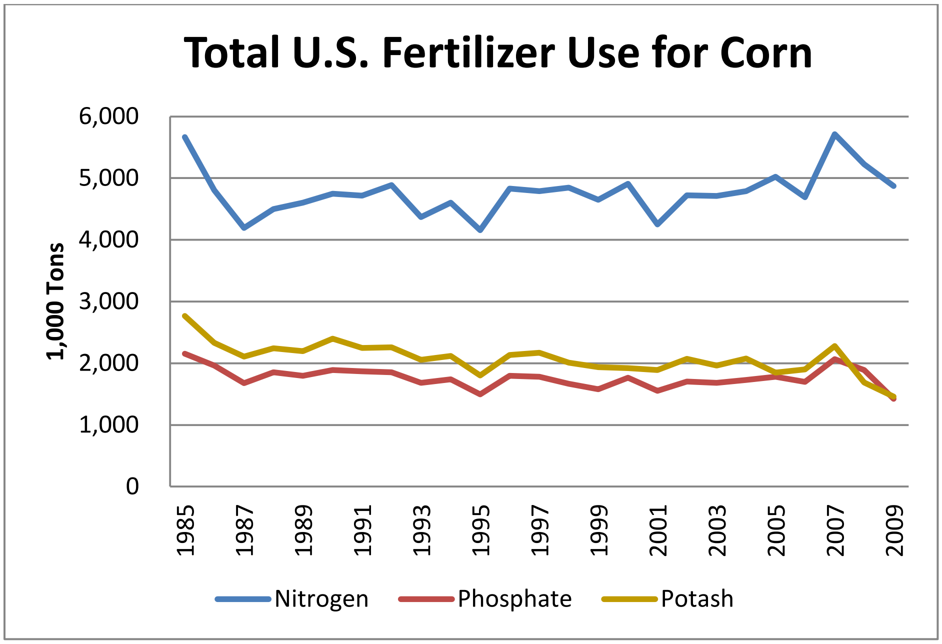
1. ***What has been the impact of the RFS on corn prices in recent years? What has been the impact on soybean prices? Have other agricultural commodity prices also been affected?***

   The impact the RFS has had on grain prices and other commodities is minimal at best. While demand for ethanol production has resulted in an overall greater demand for corn, farmers have been able to meet much of this demand by producing greater yields from fewer acres, following improvements made possible because of biotechnology. This has minimized the need for crop expansion. U.S. yields of corn have risen consistently, with fewer fluctuations since introduction of biotech seed in 1995. Leading scientists have calculated, "the food-fuel dilemma could be avoided if we took full advantage of biotechnology, which would lead to increased supply and reduced agricultural commodity prices."[4]

[3] U.S. Energy Information Administration. 28 Sep. 2012. *Increases in oil prices affect broader measures of inflation.* http://www.eia.gov/todayinenergy/detail.cfm?id=8170
[4] FutureScience. Nov. 2012. *Ask the Experts: The food versus fuel debate*. Biofuels 3(6) 635-648. http://www.future-science.com/doi/abs/10.4155/bfs.12.59



In 2012, crops improved by agricultural biotechnology were being grown in 28 countries by more than 17 million farmers, across 421 million acres. Currently, the vast majority of these crops have traits that make them resistant to destructive pests and diseases, and that enable farmers to control weeds better, using more environmentally friendly farming practices that improve carbon storage and water retention in the soil. Adoption of biotechnology enables more sustainable techniques such as no-till cultivation that further reduce the need for petroleum inputs. This is evident with fertilizer input remaining relatively constant, compared to the increase in yields, meaning they have dropped per unit of output.



Commodity prices have also been affected by an ever-increasing global population. As world's population heads toward 9 billion people by 2050, demand for food, energy, and material resources is expected to increase at an even faster rate, due to increased demand for dietary protein and consumer goods. Feeding more livestock and poultry will require additional agricultural productivity and diversity. However, biofuel production can help toward this goal with a growth in supply of ethanol co-products to help mitigate the impact in feed prices.[5] Most notable of these co-products is distillers dried grains with soluble (DDGs), which can be used as a feed ingredient for livestock. Each 56-pound bushel of corn used in dry-mill ethanol production generates about 17.4 pounds of DDGs. In many cases, these DDGs can provide an excellent energy and protein source for livestock and provide a greater energy value than dry-rolled corn. In the example of beef cattle, using DDGs has 102 percent to 127 percent the energy value of the same amount of corn; and numerous other studies have shown DDGs can be a value added component to both poultry and swine feed. When formulated in the right amounts DDGs can help reduce feed costs, while increasing animal health, performance, and quality.[6]

The change in the use of corn *grain* for feed is similar to changes in uses of other grains in the past. Animal producers have fed fewer grains of any type. Use of biorefinery/mill byproduct feeds, such as oil seed meal and corn DDGs, has increased since the 1985, benefiting producers by giving them greater options and market flexibility.

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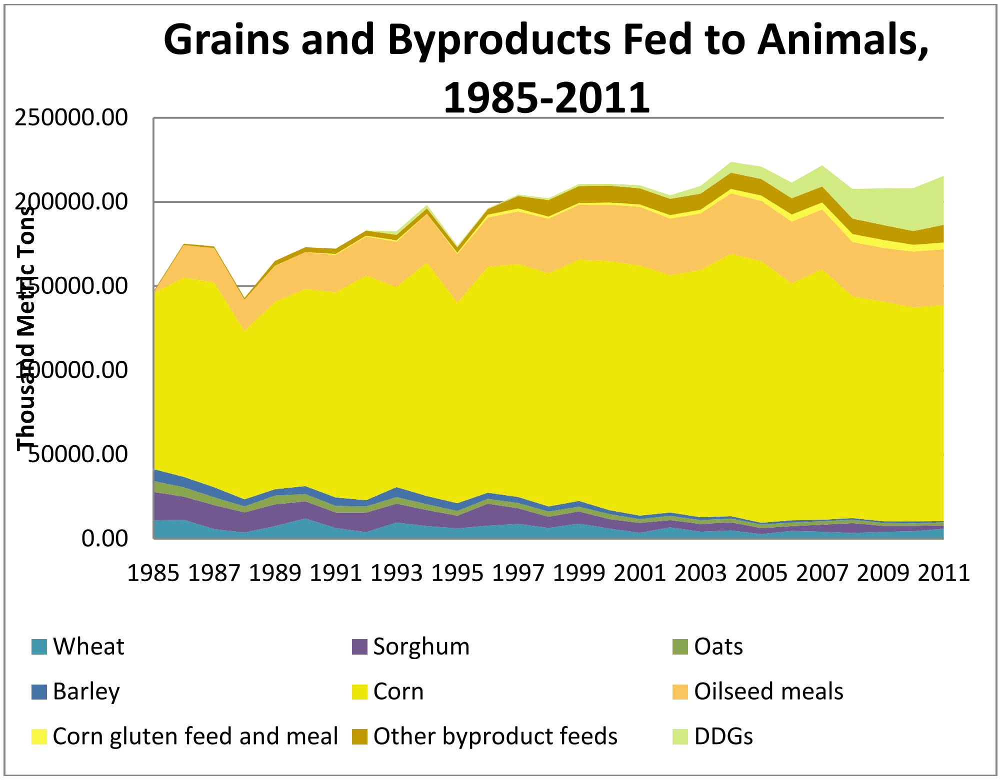
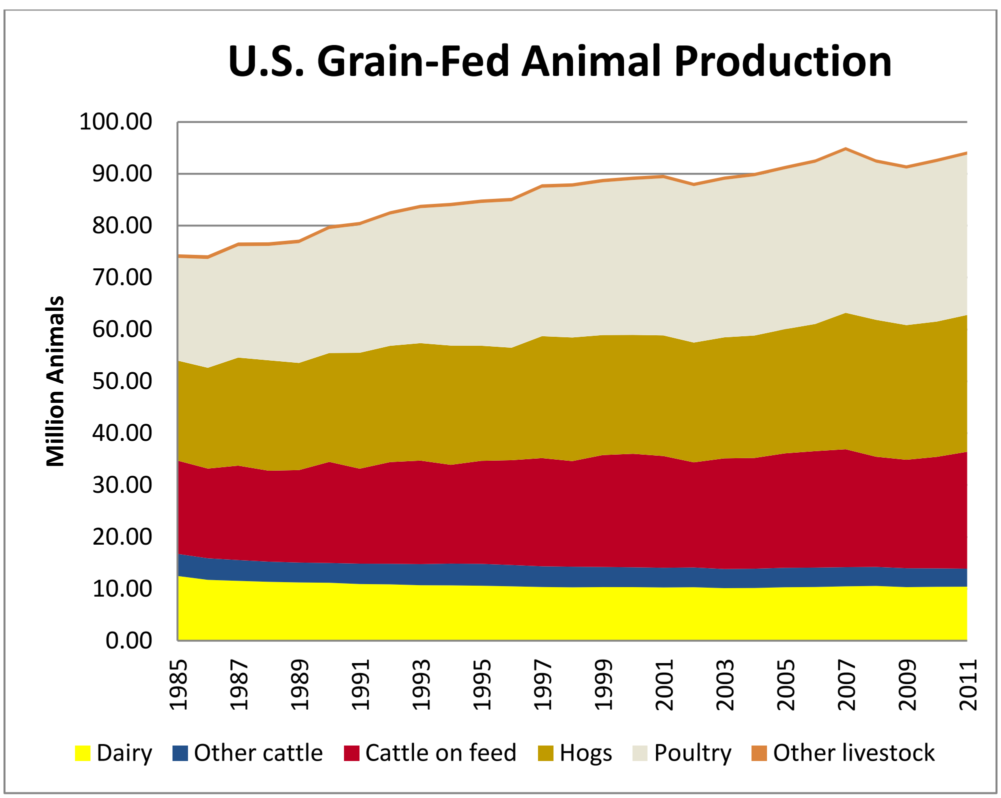
[5] FAO**.** 2012. *Biofuel co-products as livestock feed - Opportunities and challenges,* edited by Harinder P.S. Makkar. Rome.
[6] U.S. Grains Council. 5 Oct. 2012. *A Guide to Distiller's Dried grains with Solubles (DDGS).*
http://www.grains.org/index.php/2012-04-30-15-22-26/3928-usgc-releases-third-edition-of-ddgs-handbook





Source: USDA Economic Research Service

Further, focusing just on the RFS ignores the biggest factor in the cost of agricultural production: the volatility in oil and energy prices. Biofuel production helps mitigate this volatility by diversifying fuel supplies. As noted in our introduction, the greatest impact on food production is oil prices. In examining the spike in commodity prices in 2008, the Development Prospects Group at the World Bank found that despite significant spikes in some food prices, biofuels production, both domestically and internationally, only accounted for about 4 percent of the 2008 cost increase, while the rapid increase in oil prices at the same time actually accounted for a much larger portion of the spikes.[7] In the 2012 edition of the *World Energy Outlook* the International Energy Agency found that the high cost of oil is putting the brakes on worldwide economic growth, increasing production costs across all sectors, including agriculture.[8]

Because of the impacts oil prices have on food production, we should allow the RFS to continue to function as intended. Maintaining the use of existing biofuels and spurring the development of advanced biofuels will help mitigate the price impacts oil has on food production. Creating more domestic energy from renewable fuels will not only improve our energy security, but also boost the rural economy through value-added production and lower cost fuels.

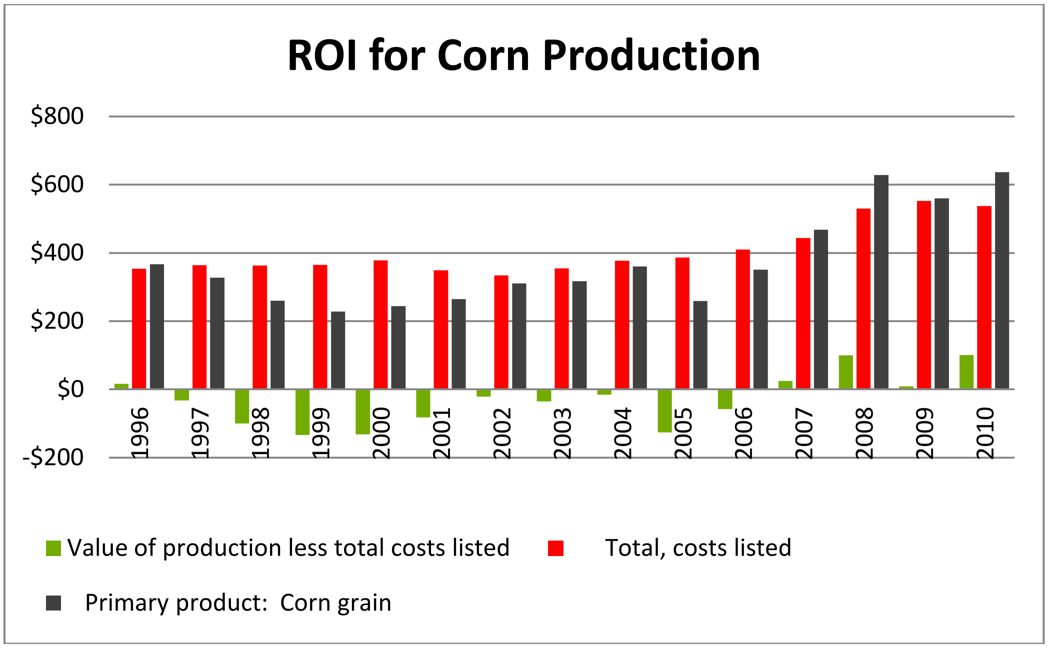
2. ***How much has the RFS increased agricultural output? How many jobs has it created? Have any jobs been lost? What is the net impact on the agriculture sector?***

A number of factors have led to increases in agriculture output, including biofuels. These include changes in agriculture policy, allowing farmers to make their own crop planting decisions based on the most profitable crop for a given year. Agriculture output has also benefitted from biotechnology improvements in seed varieties and fertilizers, which allow farmers to use fewer inputs such as fuel, fertilizer, and water by enabling crops to withstand pests and variations in the weather.[9]

Increases in foreign trade have also benefitted agriculture. Not only is the U.S. the world's largest corn producer, it currently exports about one-fifth of annual production. With continued population increases and consumer demand for meat products, feed grain exports could grow over the long-term.[10]

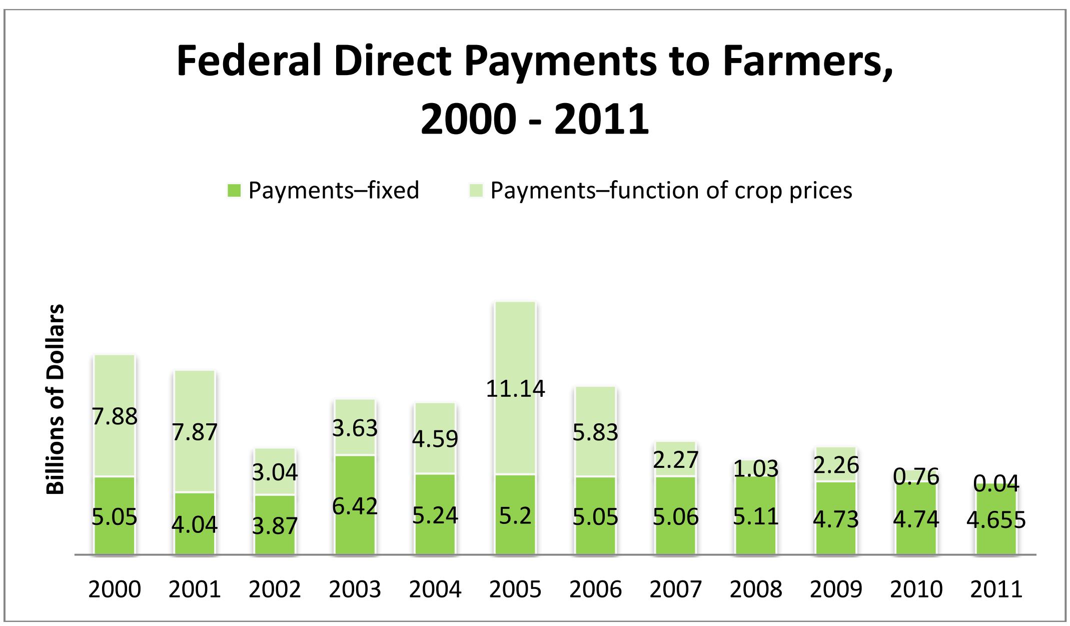
However, the RFS and biofuels as a whole have had an overall positive impact on agricultural output and the rural economy. After a decade of high costs and low returns, the return on corn production has been positive since 2007, with ethanol giving corn producers the additional markets they need to remain profitable.

[7] The World Bank Development Prospects Group. July 2010. *Placing the 2006/08 Commodity Price Boom into Perspective.* http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2010/07/21/000158349_20100721110120/Rendered/PDF/WPS5371.pdf
[8] International Energy Agency. 12 Nov. 2012. *World Energy Outlook 2012*. http://www.worldenergyoutlook.org/publications/weo-2012/#d.en.26099
[9] USDA Economic Research Service. 16 Apr. 2013. *Corn Background*. http://www.ers.usda.gov/topics/crops/corn/background.aspx#.UXbkPKLvtBc
[10] USDA Economic Research Service. 16 Apr. 2013. *Corn Trade* http://www.ers.usda.gov/topics/crops/corn/trade.aspx#.UXfZd6LvtBc



Source: USDA Economic Research Service

At the same time, ethanol production has helped the government save money by increasing demand for corn and raising the price to an equitable market value, reducing the need for farm payments.[11]



Source: USDA NASS

[11] USDA Economic Research Service. 30 May 2012. *Farm and Commodity Policy Overview.* http://www.ers.usda.gov/topics/farm-economy/farm-commodity-policy.aspx#.UXfd7KLvtBc

In addition to grain producers, continuing to build advanced biofuels production capacity can benefit the broader rural economy, creating thousands of new jobs, contributing to U.S. economic growth and increasing energy security, according to a report by Bio Economic Research Associates (bio-era^{tm}), *U.S. Economic Impact of Advanced Biofuels production: Perspectives to 2030* (Appendix I). According to the report, direct job creation from advanced biofuels production could reach 190,000 by 2022, and total job creation, accounting for economic multiplier effects, could reach 807,000 by 2022. The report found that cumulative investment in new processing facilities driven by the RFS could total more than $95 billion by 2022. At the same time, advanced biofuels production under the RFS could reduce U.S. petroleum imports by approximately $70 billion by 2022, with a cumulative total of avoided petroleum imports over the period of 2010-2022 exceeding $350 billion.

3. ***Was EPA correct to deny the 2012 waiver request? Are there any lessons that can be drawn from the waiver denial?***

The U.S. Environmental Protection Agency (EPA) made the correct determination last fall in its decision to deny the requests to waive the RFS made by members of *Smarter Fuel Future* and the governors of 12 states. The EPA tested 500 scenarios combining different corn, oil, and biofuel production price points.[12] In 89 percent of the scenarios, EPA found that biofuel production would remain at its current level because high oil prices drive demand for lower-cost alternatives. In the other 11 percent of scenarios where biofuel production dropped due to a waiver of the RFS, EPA emphasized that the combination of "projected fuel prices and corn yields are both unrealistically low." Gasoline prices would have to drop below $2.00 a gallon wholesale before demand for biofuel would decrease.

The conclusion reached by EPA mirrors the findings of several independent academic studies, including one by Purdue University and the Farm Foundation,[13] another by Iowa State University,[14] and a third by the University of Missouri.[15] Notably, the Purdue study found that a waiver of the RFS could not change the economic losses already caused by the drought.

4. ***Does the Clean Air Act provide EPA sufficient flexibility to adequately address any effects that the RFS may have on corn price spikes?***

As discussed in Question 3, the EPA and a number of independent academic studies found the RFS had little to do with the spike in corn prices. As discussed in the Iowa State University paper examining the RFS waiver, "The flexibility built into the RFS allowing obligated parties to carry over Renewable Identification Number (RIN) blending credits from previous years significantly lowers the economic impacts of a short crop…relaxing the mandate further would have modest impacts on corn prices."

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[12] U.S. Environmental Protection Agency. 27 Nov. 2012. *Notice of Decision Regarding request for a Waiver of the Renewable Fuel Standard*. http://www.gpo.gov/fdsys/pkg/FR-2012-11-27/pdf/2012-28586.pdf

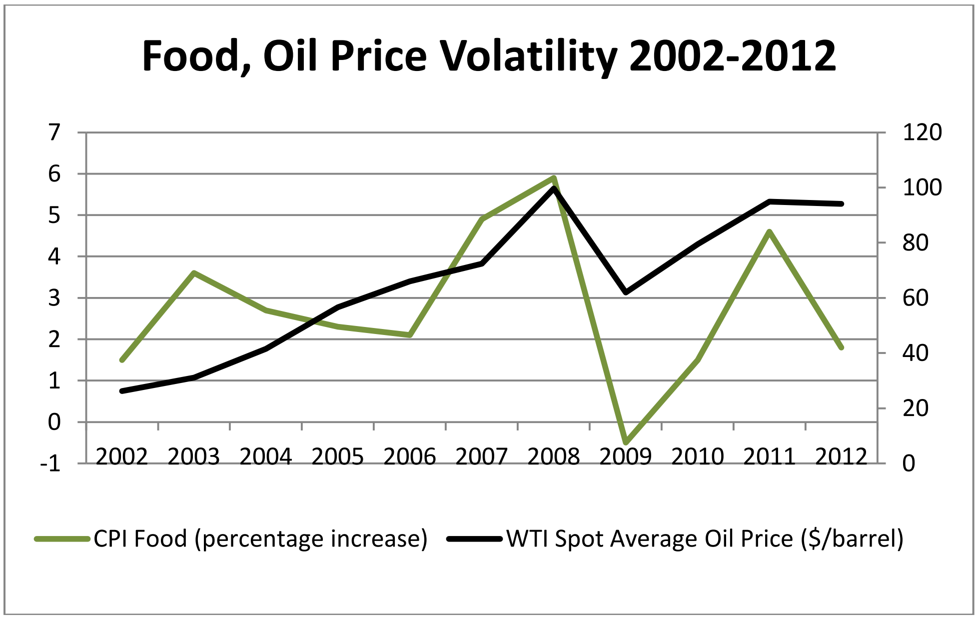
[13] Farm Foundation and Purdue University. 2012. *Potential Impact of a Partial Waiver of the Ethanol Blending Rules.* *http://www.farmfoundation.org/news/articlefiles/1841-Purdue%20paper%20final.pdf*

[14] Center for Agricultural and Rural Development, Iowa State University. Aug. 2012. *Updated Assessment of the Drought's Impact on Crop Prices and Biofuel Production*. http://www.card.iastate.edu/publications/ dbs/pdffiles/12pb8.pdf

[15] Food and Agricultural Policy Research Institute, University of Missouri. Oct. 2012. Renewable Fuel Standard Waiver Options during the Drought of 2012. http://www.fapri.missouri.edu/outreach/publications/2012/ FAPRI_MU_Report_11_12.pdf

5. *What has been the impact, if any, of the RFS on food prices?*

Increases in the Consumer Price Index for Food since 2002 track closely to increases in the prices of oil and gasoline. Numerous studies show that oil, weather, and the value of U.S. currency are the greatest contributors to food price volatility.



At the same time, while conventional biofuel production has increased rapidly since 2005, it is not strongly correlated to food price inflation.

As former-USDA Energy Advisor Sarah Bittleman noted last fall, a host of factors affect food prices, and it makes no sense to pin a rise on food prices to the RFS. Food prices are subject to commodity, labor, transportation, energy costs, processing, and marketing. She went on to note,

> USDA's Economic Research Service estimates that farmers receive about 14.1 percent of the total consumer food dollar (based on the 2010 average food dollar). This suggests that if the price of all food commodities were to double at the farm level, and other production processes were held fixed, food inflation would rise just over 14 percent.
>
> However, the chance of all other production processes, such as the cost of energy, remaining fixed, are small. That is why America must continue to invest in the homegrown renewable energy that will help balance rising energy costs. Being able to produce more domestic energy from all sources, including renewable fuels, will improve energy security, boost the rural economy and keep the cost of traditional fuels lower. For example, when Hurricane Katrina damaged oil and refining capacity

in the Gulf, the Department of Energy estimated that ethanol reduced the price of gasoline between $0.25 and $0.35 per gallon.[16]

Also, as we discussed earlier in the paper it has been demonstrated that the price of oil has the greatest impact on food inflation – and most other measures of inflation – according to the U.S. Energy Information Administration. The Development Prospects Group at the World Bank, when examining the spike in commodity prices in 2008, determined that despite the significant spike in some food prices, biofuels production, both domestically and internationally, only accounted for about 4 percent of the 2008 cost increase, while the rapid increase in oil prices at the same time actually accounted for a much larger portion of the spikes.

6. ***What role could cellulosic biofuels play in mitigating the potential effects of the RFS on corn prices?***

The further development of cellulosic and other advanced biofuels will help corn producers with their greatest input cost, fuel. As discussed in *U.S. Economic Impact of Advanced Biofuels production: Perspectives to 2030*, advanced biofuels production under the RFS scenario could reduce U.S. petroleum imports by approximately $5.5 billion in 2012, $23 billion in 2016, and nearly $70 billion by 2022. The cumulative total of avoided petroleum imports over the period 2010–2022 would exceed $350 billion.

By helping to lower fuel prices by lessening dependence on foreign oil, cellulosic biofuels can help lower the cost of production on the farm, transportation, and other cost factors in grain production dependent on foreign fuels such as fertilizer and graining drying.

Cellulosic biomass is the most abundant, and potentially the lowest cost, source of renewable energy. To capitalize on this resource, the United States must develop and mature commodity markets and supply chains for growing, harvesting, and transporting cellulosic biomass or cellulosic sugars – similar to other commodity markets. Programs in the Energy Title of the Farm Bill, such as the Biomass Crop Assistance Program, are the only existing policies to support the development of these supply chains and commodity markets. Reauthorization and robust funding for the Energy Title should be considered in legislation to renew or extend the existing Farm Bill.

7. ***What impact are cellulosic biofuels expected to have on rural economies as the production of such fuels ramps up?***

According to the study *U.S. Economic Impact of Advanced Biofuels production: Perspectives to 2030*, cellulosic and advanced biofuels will have a positive impact on both rural economies and the nation's economy as a whole. Key finding in the analysis yielded the following:

- Direct job creation from advanced biofuels production could reach 29,000 by 2012, rising to 94,000 by 2016 and 190,000 by 2022. Total job creation, accounting for economic multiplier effects, could reach 123,000 in 2012, 383,000 in 2016, and 807,000 by 2022.

[16] USDA Blog. 30 Nov. 2012. *Energy Advisor Says a Host of Factors Affect Food Prices*. http://blogs.usda.gov/2012/11/30/energy-advisor-says-a-host-of-factors-affect-food-prices/

- Investments in advanced biofuels processing plants alone would reach $3.2 billion in 2012, rising to $8.5 billion in 2016, and $12.2 billion by 2022. Cumulative investment in new processing facilities between 2009 and 2022 would total more than $95 billion.

- Direct economic output from the advanced biofuels industry, including capital investment, research and development, technology royalties, processing operations, feedstock production and biofuels distribution, is estimated to rise to $5.5 billion in 2012, reaching $17.4 billion in 2016, and $37 billion by 2022.

- Taking into consideration the indirect and induced economic effects resulting from direct expenditures in advanced biofuels production, the total economic output effect for the U.S. economy is estimated to be $20.2 billion in 2012, $64.2 billion in 2016, and $148.7 billion in 2022.

- Advanced biofuels production under the RFS scenario could reduce U.S. petroleum imports by approximately $5.5 billion in 2012, $23 billion in 2016, and nearly $70 billion by 2022. The cumulative total of avoided petroleum imports over the period 2010–2022 would exceed $350 billion.

The Bio-era model was also used to assess the economic implications of a scenario in which total U.S. biofuels production grows to 60 billion gallons by 2030, with 15 billion gallons of conventional biofuels production and 45 billion gallons of advanced biofuels production. This analysis concludes that:

- Approximately 400,000 jobs would be directly created in the advanced biofuels industry, with total employment creation in the U.S. economy totaling 1.9 million jobs.

- Direct economic output from advanced biofuels production would rise to $113 billion by 2030. The total economic output effect would be $300 billion.

- Biomass feedstocks in this scenario could be provided by a mix of agricultural and forest wastes and dedicated energy crops, providing a total of 470 million dry tons of biomass by 2030 using existing crop and forest land.

- The average cost of advanced biofuel production at the plant-gate in 2030 would be $1.88 including all operating costs, overhead, and capital recovery.

A recent study from Oak Ridge National Laboratories[17] reaffirmed many of these findings, showing that growth of biofuel production under the RFS could:

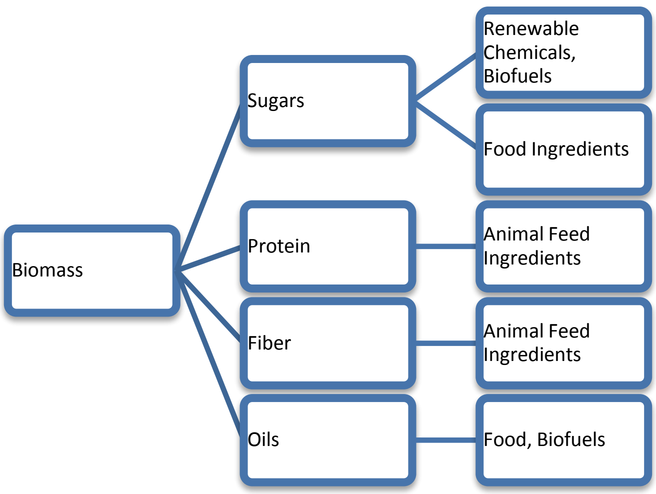
- Displace about 20 percent of oil imports by 2022;

- Reduce GHG emissions relative to oil-based fuels;

[17] Oladosu, G. et al. "Global economic effects of US biofuel policy and the potential contribution from advanced biofuels." Biofuels20123:6, 703-723

- And promote economic growth here in the United States and, to a moderate extent, around the world.

The development of biorefineries for cellulosic and advanced biofuels and renewable chemicals will also leverage increasing agricultural productivity and industrial biotechnology innovation to create a robust, sustainable bioeconomy. Integrated biorefineries make multiple products from biomass streams, much as oil refineries make multiple products from petroleum. Using biomass efficiently, reusing waste streams and increasing productivity and yields are the keys to sustainability.



8. *Will the cellulosic biofuels provisions succeed in diversifying the RFS?*

The cellulosic biofuels provisions will succeed in diversifying the RFS, if Congress leaves the RFS in place to function properly. The current RFS goals from the 2007 Energy Independence and Security Act have only been in place for five-years, just one-third of the Standard's 15 year ramp up. The rules for the RFS were only finalized in March 2010 and came into effect in July 2010, meaning the law has only been in effect less than three years. Unfortunately, implementation of the standard has been delayed and slowed down not just by the economic downturn beginning in 2008, but by a number of regulatory delays, including EPA's approval of new feedstocks for the cellulosic and advanced biofuels. Any changes to the RFS would create regulatory and financial uncertainty for the industry, destabilizing an industry that has spurred billions of dollars of investment and helped to create more than 400,000 jobs in the U.S. and has the potential to create up to 800,000 within 10-years.

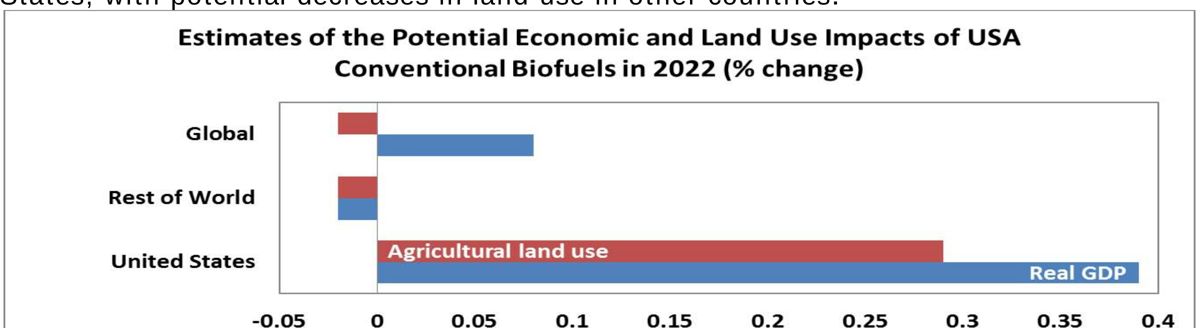
9. ***What is the scale of the impact of the RFS on international agricultural production and global land use changes?***

As mandated by EISA, EPA has analyzed lifecycle GHG emissions from increased renewable fuels use. EISA defines lifecycle GHG emissions as follows:

> The term 'lifecycle greenhouse gas emissions' means the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions ***such as significant emissions from land use changes***), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential.

In its final rule implementing the RFS, *Regulation of Fuels and Fuel Additives: Change to Renewable Fuel Standard Program,* EPA's findings showed less land is needed domestically and globally for crops as biofuels expand than they had initially assumed.[18] This is possible because of the rate of improvement in crop yields through technology gains. Additional byproducts that can be developed from a biorefinery, such as DDGs can offset a decrease in grain availability.

Further, the U.S. Departments of Energy and Agriculture found that we can grow adequate biomass feedstocks to displace approximately 30 percent of current gasoline consumption by 2030 on a sustainable basis with only modest changes in land use.[19] It determined that the 1.23 billion tons of U.S. biomass feedstock is potentially available for the production of biofuels, more than enough biomass to meet the RFS. This would provide a positive economic effect on the U.S. economy with a neutral effect on global land use. The Oak Ridge study in 2013 determined that this land use change would occur within the United States, with potential decreases in land use in other countries.[20]



	United States	Rest of World	Global
Agricultural land use	0.29	-0.02	-0.02
Real GDP	0.39	-0.02	0.08

Change in Regional Gross Domestic Product and Agricultural Land Use (%)

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[18] U.S. Environmental Protection Agency. 26 Mar. 2010. *Regulation of Fuels and Fuel Additives: Change to Renewable Fuel Standard Program*. http://www.gpo.gov/fdsys/pkg/FR-2010-03-26/pdf/2010-3851.pdf

[19] U.S. Department of Energy. Apr. 2005. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply* http://www1.eere.energy.gov/biomass/pdfs/ final_billionton_vision_report2.pdf

[20] Oladosu, G. et al.

Conclusion:

As we have demonstrated throughout our response, the biggest impact to agriculture production, feed cost for livestock, and consumer food costs is the volatile price of oil. Through the mandate of the RFS and the increased use of biotechnology, we are beginning to see the rapid development of biofuels and the biobased economy, which can help mitigate the volatility energy prices cause to commodities, transportation, energy costs, and processing.

The RFS is spurring the development of biotechnology in agriculture, which can continue to increase productivity for corn and other grains without increasing fertilizer and chemical loads, which is a key to sustainably meeting demand. Grain farmers will always seek markets for grain that add the most value, and biotechnology can add value to the sugar and proteins from grains and create new markets. At the same time, biotechnology can help animal producers impacted by feed prices, since biorefineries can produce *value-added* animal feed *and* biofuels, renewable chemicals, and biobased products.

Biofuels continue to help bring stability to the fuel market. And with the RFS spurring the development of the second generation of biofuels, they will reduce the need to import foreign fuel saving the country $350 billion by 2022. At the same time, development of biorefineries for cellulosic and advanced biofuels and renewable chemicals will also leverage increasing agricultural productivity and industrial biotechnology innovation to create a robust, sustainable bioeconomy. Integrated biorefineries make multiple products from biomass streams, much as oil refineries make multiple products from petroleum. Using biomass efficiently, reusing waste streams and increasing productivity and yields are the keys to sustainability and job growth.

So in conclusion Chairman Upton and Ranking Member Waxman, we would encourage you not to look at the RFS has an impediment to agriculture, but view it as a driver of developing sustainable food, feed, fiber, biofuels, renewable chemicals, and bioproducts which can be produced in American helping rural communities grow their job base.

Thank you for your consideration.

Sincerely,

Brent Erickson

Brent Erickson
Executive Vice President
Industrial and Environmental Section
Biotechnology Industry Organization

bio-era
BIO ECONOMIC RESEARCH ASSOCIATES

U.S. ECONOMIC IMPACT OF ADVANCED BIOFUELS PRODUCTION:

PERSPECTIVES TO 2030

FEBRUARY 2009

bio-era
BIO ECONOMIC RESEARCH ASSOCIATES

U.S. Economic Impact of Advanced Biofuels Production: Perspectives to 2030

February 2009

Executive Summary

The U.S. Renewable Fuel Standard (RFS) for transportation fuels sets minimum levels of renewable fuels that must be blended into gasoline and other transportation fuels from 2006 to 2022. Specific requirements for blending advanced biofuels,** including cellulosic biofuels and biomass-based biodiesel, begin at 0.6 billion gallons per year in 2009 and rise to 21 billion gallons in 2022. The RFS levels for advanced biofuels production will drive the creation of a major new industry, creating a foundation for future technology development and commercial growth.

To estimate the economic implications of the emergence of this new industry, bio-era conducted a meta-analysis of nearly two dozen studies of economic impacts of biofuels production, developed a model to analyze economic output and job creation, and applied this model to analyze the economic impact of increasing U.S. advanced biofuel production to 21 billion gallons per year by 2022.

This analysis yielded the following conclusions:

- Direct job creation from advanced biofuels production could reach 29,000 by 2012, rising to 94,000 by 2016 and 190,000 by 2022. Total job creation, accounting for economic multiplier effects, could reach 123,000 in 2012, 383,000 in 2016, and 807,000 by 2022.
- Investments in advanced biofuels processing plants alone would reach $3.2 billion in 2012, rising to $8.5 billion in 2016, and $12.2 billion by 2022. Cumulative investment in new processing facilities between 2009 and 2022 would total more than $95 billion.
- Direct economic output from the advanced biofuels industry, including capital investment, research and development, technology royalties, processing operations, feedstock production and biofuels distribution, is estimated to rise to $5.5 billion in 2012, reaching $17.4 billion in 2016, and $37 billion by 2022.

** This research was carried out independently by bio-era, with financial support from the Industrial & Environmental section of the Biotechnology Industry Organization (BIO), February 2009.*

***As defined by the Energy Independence and Security Act of 2007, advanced biofuels are renewable fuels, other than ethanol derived from corn starch, that have lifecycle greenhouse gas emissions that achieve at least a 50 percent reduction over baseline lifecycle greenhouse gas emissions. Advanced biofuels may include ethanol derived from cellulose or lignin, sugar or starch (other than corn starch), or waste material, including crop residue, other vegetative waste material, animal waste, and food waste and yard waste; biomass-based diesel; biogas produced through the conversion of organic matter from renewable biomass; butanol or other alcohols produced through the conversion of organic matter from renewable biomass; and other fuel derived from cellulosic biomass.*

- Taking into consideration the indirect and induced economic effects resulting from direct expenditures in advanced biofuels production, the total economic output effect for the U.S. economy is estimated to be $20.2 billion in 2012, $64.2 billion in 2016, and $148.7 billion in 2022.

- Advanced biofuels production under the RFS scenario could reduce U.S. petroleum imports by approximately $5.5 billion in 2012, $23 billion in 2016, and nearly $70 billion by 2022. The cumulative total of avoided petroleum imports over the period 2010–2022 would exceed $350 billion.

The bio-era model was also used to assess the economic implications of a scenario in which total U.S. biofuels production grows to 60 billion gallons by 2030, with 15 billion gallons of conventional biofuels production and 45 billion gallons of advanced biofuels production. This analysis concludes that:

- Approximately 400,000 jobs would be directly created in the advanced biofuels industry, with total employment creation in the U.S. economy totaling 1.9 million jobs.

- Direct economic output from advanced biofuels production would rise to $113 billion by 2030. The total economic output effect would be $300 billion.

- Biomass feedstocks in this scenario could be provided by a mix of agricultural and forest wastes and dedicated energy crops, providing a total of 470 million dry tons of biomass by 2030 using existing crop and forest land.

- The average cost of advanced biofuel production at the plant-gate in 2030 would be $1.88 including all operating costs, overhead, and capital recovery.

Introduction

The emergence of a new advanced biofuels production industry over the next two decades portends significant economic value creation and jobs growth. Although it is early to predict the exact character and dimensions of these impacts, detailed studies of advanced biofuels production processes conducted in recent years provide a foundation for predicting the potential size of economic impacts on the U.S. economy resulting from the growth of this new industry.

In this analysis, we estimate the U.S. economic impact of advanced biofuels production at the levels mandated by the Energy Independence and Security Act of 2007 (EISA). Under EISA, advanced biofuels production will rise from 2.0 billion gallons per year (BGY) in 2012 to 21.0 BGY in 2022 (Figure 1). We compare the economic impact of this trajectory to one in which there is no advanced biofuels production in the United States through 2022.

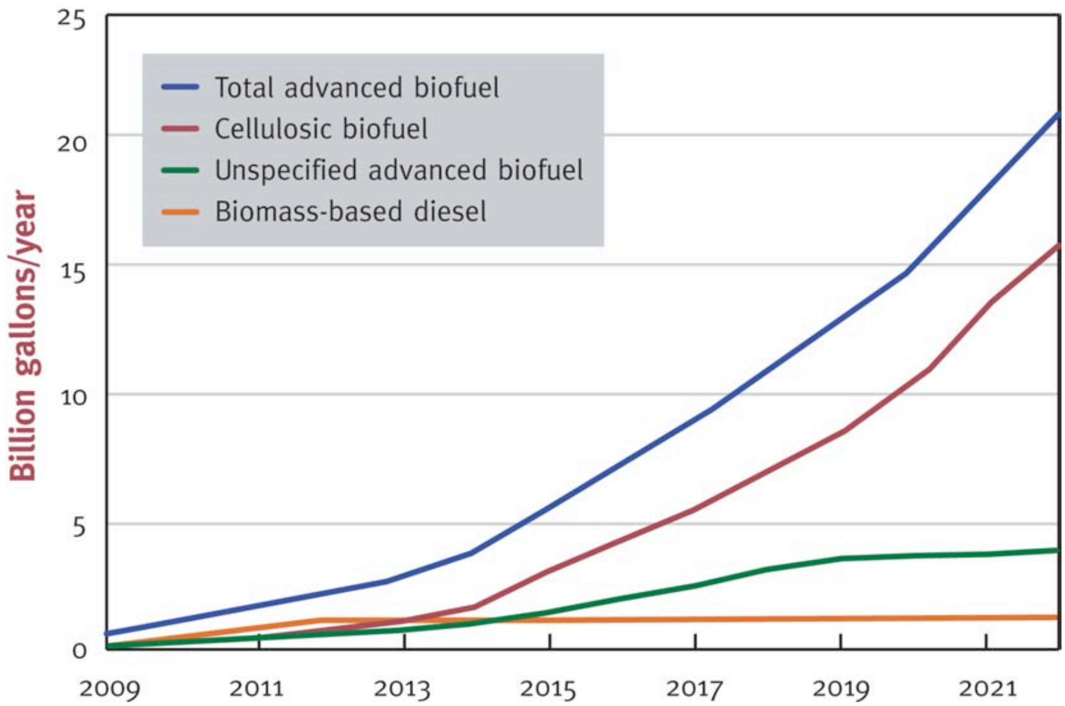


Figure 1: U.S. Production of Advanced Biofuels under the Renewable Fuel Standard

Analysis Approach

Numerous studies have been conducted to measure the economic impacts of biofuels production in terms of economic output and job creation. These studies span a wide range in terms of scope, from individual biofuels processing plants to groups of plants and ancillary operations at the state, regional, or national level.[1] For example, Perez-Verdin (2008), Flanders (2007), Solomon (2007), and Leistritz (2007) have provided thorough and detailed analyses of individual biofuels processing plants for specific state or regional economies. Other studies, including Massachusetts Advanced Biofuels (2008), Leistritz (2008), and Swenson (2007) assess the impacts of multiple plants on a regional or national basis.

Existing studies also consider a wide range of different biofuels processing technologies and feedstock supply options, including various biological and thermochemical conversion processes and feedstocks ranging from crop and forest residues to switchgrass, Miscanthus, and short-rotation woody crops. Finally, several different types of economic models have been used to analyze the total economic impact of biofuels production, including IMPLAN, RIMS II, and Policy Insight.

In this study, we conduct a meta-analysis of nearly two dozen existing studies to provide a foundation for creating key working assumptions about advanced biofuels production operations and the economic multiplier effects related to those operations (see Appendix for further details). We use these assumptions to model the economic impact of the scale-up of advanced biofuels operations, including technology development, plant engineering, procurement, and construction, processing operations, feedstock supply, and biofuels distribution.

Model Assumptions

Advanced biofuels processing capacity and investment. To meet the RFS requirements, we estimate that advanced biofuels production capacity will need to rise to more than 23 billion gallons by 2022, requiring a cumulative capital investment in processing capacity of more than $95 billion. Annual capital investments in advanced biofuels processing plants would rise from $2.0 billion in 2011 to $8.5 billion in 2016 and $12.2 billion in 2022. Figure 2 and Table 1 summarize our assumptions about the capital costs per gallon of installed capacity for cellulosic ethanol plants, the distribution of capacity across various sizes of plants, and the total capital investment in biofuels processing capacity. We assume a capacity utilization factor of 90 percent for advanced biofuels plants. This is comparable to the capacity utilization for petroleum refineries, which averaged 89.5 percent from 1985 to 2007, and that for corn-based ethanol plants, which typically operate at average utilization rates of 90–95 percent.

Processing plants will likely span a wide range of sizes, with most facilities between 20 and 200 million gallons of annual capacity. Smaller plants will have the advantage of shorter haul distances for feedstocks, at least where energy crops are being grown to supply biomass to the plant. On the other hand, economies of scale in engineering, construction, and permitting may make the capital costs per unit of capacity lower for larger plants.

Table 1: Cellulosic Ethanol Processing Plants*

Year	Total installed capacity (BGY) by size of plant				Number of plants operating	Cellulosic ethanol production capacity operating
	20 MGY	50 MGY	100 MGY	200 MGY		
2009	0.0	0.1	0.0	0.0	3	0.1
2010	0.1	0.1	0.1	0.0	7	0.3
2011	0.1	0.2	0.2	0.0	13	0.6
2012	0.2	0.4	0.4	0.0	24	1.1
2013	0.4	0.8	0.8	0.0	43	1.9
2014	0.6	1.2	1.2	0.0	67	3.1
2015	1.0	2.0	2.0	0.0	110	5.0
2016	1.4	2.8	2.8	0.0	153	6.9
2017	1.8	3.6	3.6	0.0	196	8.9
2018	1.7	4.4	4.4	0.6	219	11.1
2019	1.3	5.3	5.3	1.3	233	13.3
2020	1.6	6.2	6.2	1.6	272	15.6
2021	1.9	7.6	7.6	1.9	331	18.9
2022	2.2	8.9	8.9	2.2	389	22.2

** Biomass-based biodiesel plants are treated separately. See Appendix for details.*

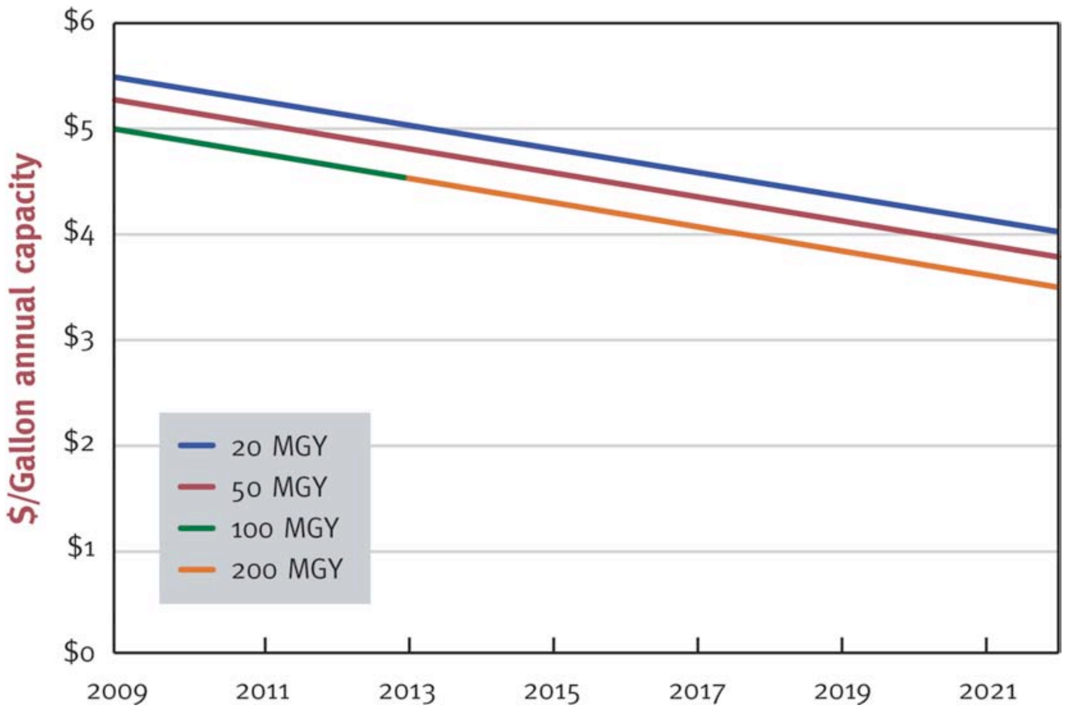


Figure 2: Average Capital Cost of Advanced Biofuels Processing Facilities ($/gallon annual capacity)

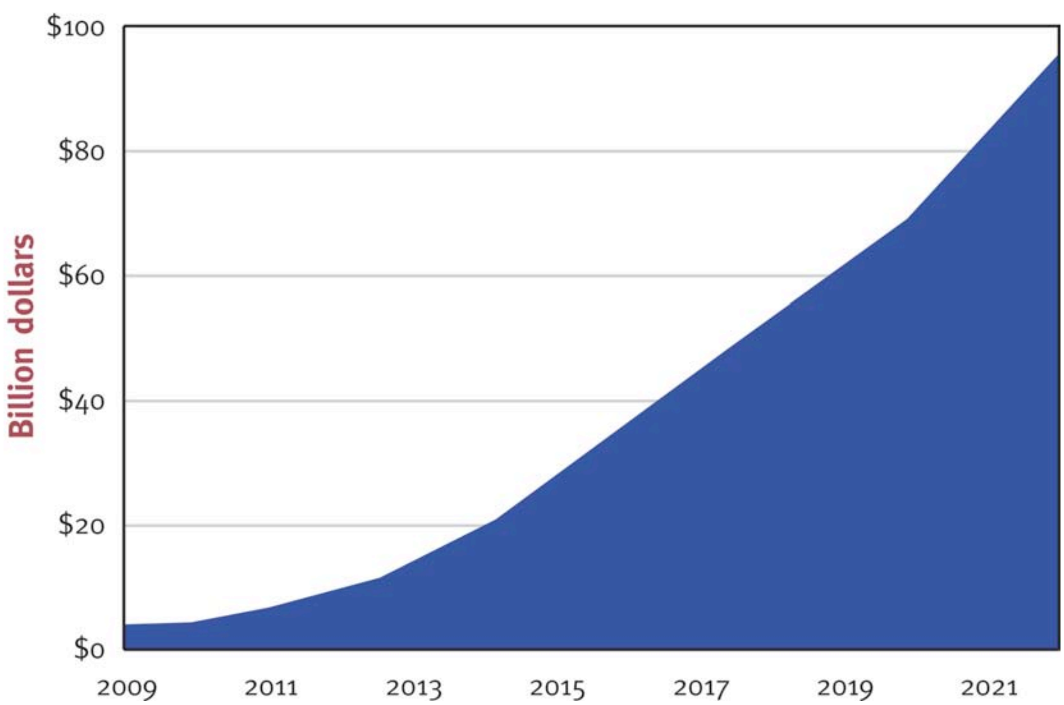
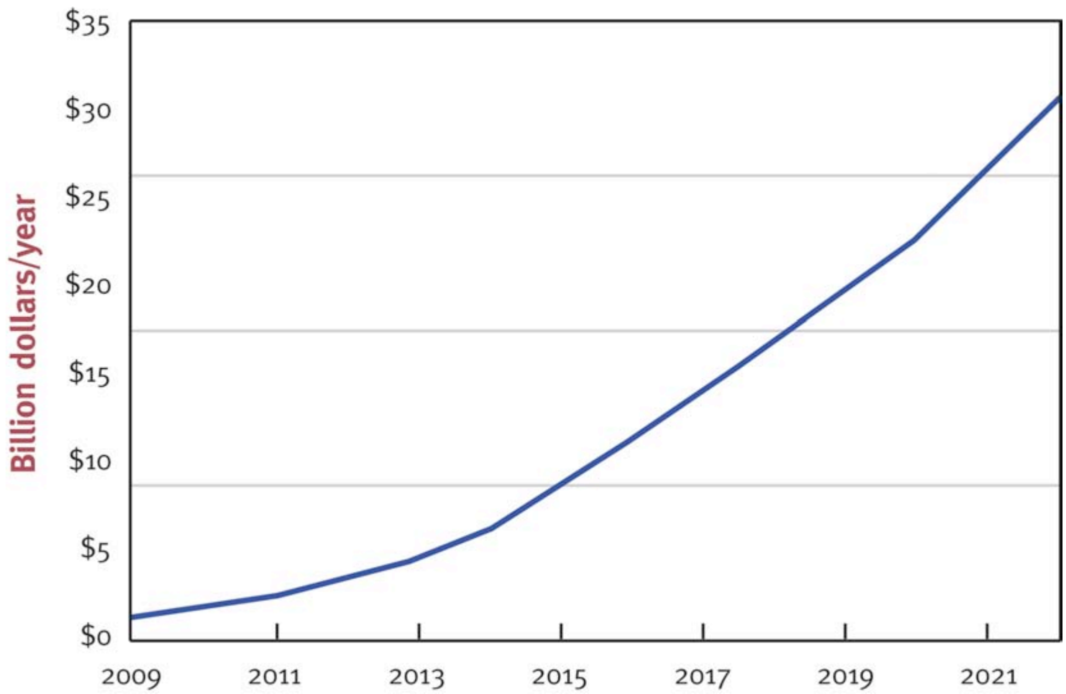


Figure 3: Cumulative Total Capital Investment in Advanced Biofuels Processing Plants

Processing operations. Based on a review of previous studies, we assume an average operating cost for advanced biofuels processing facilities, including feedstock purchases and excluding capital recovery, of $1.65 per gallon of biofuels produced in 2009 falling to $1.45 per gallon in 2022 as processes improve over time. These costs include feedstock procurement and all other operating costs but exclude capital recovery. On this basis, we project total operating expenditures for all advanced biofuels production to rise to $3.2 billion in 2012, $11.2 billion in 2016, and $30.5 billion in 2022.

Figure 4: Direct Expenditures on Advanced Biofuels Processing Operations



Feedstocks. Lignocellulosic feedstocks for advanced biofuels production are likely to come from a wide variety of sources, including crop wastes, forest residues, urban wood waste, and dedicated energy crops. Various analyses have been undertaken to create scenarios for biomass supply to meet U.S. advanced biofuels production requirements.[2] For example, a recent study funded by the U.S. Biomass Research and Development Initiative (BRDI) created detailed scenarios of possible feedstock supplies to 2022 from cropland and forestland biomass, mill residues, and municipal solid waste. The economic, geographic, and environmental implications of these different feedstock supply scenarios could diverge significantly. But it is too early to be able to accurately predict the combination of feedstock supplies that is likely to evolve to support the U.S. biofuels industry in the future.

To estimate economic impacts and job creation, at least to a first order approximation, we adopt a simplifying assumption that all cellulosic feedstock for advanced biofuels production is supplied from dedicated energy crops. We assume an average price of $55 per dry ton for biomass supplied to processing facilities beginning in 2009, falling to $50 per ton after 2013 as agricultural practices, yields, and harvesting processes improve. By comparison, a recent study by the Biomass Research and Development Initiative (2008) estimated total feedstock production costs, including harvest costs, for short-rotation woody crops to be $39–58 per dry ton. We assume 5.6 full-time equivalent (FTE) new jobs created in feedstock seed production, energy crop production, harvesting, transportation and storage for every 1,000 acres of dedicated energy crops cultivated.[3]

Based on these assumptions, farm sector employment related to feedstock production, harvesting, and transportation would increase to 88,000 by 2022, while the total value of feedstock produced would exceed $11 billion in that year (Table 2).

Table 2: Job Creation and Economic Value of Cellulosic Feedstock Production

Year	Tons of biomass per acre* (t/acre)	Gallons biofuels per ton feedstock (gal/ton)	Dollars per ton feedstock ($/bdt)	Total feedstock jobs at RFS levels (thousand)	Value of feedstock produced (billion dollars)
2009	7	77	55	6.2	0.4
2010	8	78	55	9.0	0.7
2011	8	80	55	11.7	0.9
2012	9	81	55	16.0	1.4
2013	9	83	50	20.4	1.7
2014	10	84	50	25.8	2.2
2015	10	85	50	35.3	3.2
2016	11	87	50	43.5	4.2
2017	11	88	50	50.6	5.1
2018	12	89	50	58.1	6.1
2019	12	91	50	64.7	7.2
2020	13	92	50	70.5	8.1
2021	13	94	50	80.0	9.6
2022	14	95	50	88.4	11.1

**Note: Average yields per acre include all land projected to be used for cultivation for energy crops in the U.S. Crops such as switchgrass and Miscanthus may take several years to reach peak production.*

Biofuels distribution. We assume average costs for transportation and distribution of biofuels from production facilities to downstream blending stations within the U.S. liquid fuel infrastructure of $0.23 per gallon. Current transportation costs for ethanol in the United States typically range from $0.18 to $0.30 per gallon.[4] On this basis, the economic value of these operations will increase to $0.5 billion in 2012 and $4.9 billion in 2022.

Research and development. Advanced biofuels producers will need to invest significantly in research and development in order to pioneer new technology applications over the next 10–15 years. Measured as a percentage of total revenues, U.S. industries' investments in R&D range widely, from 13.6 percent for software to 7 percent for consumer electronics to 1 percent for energy and chemicals.[5] We assume that the advanced biofuels sector will spend 5.5 percent of revenues on R&D in the period prior to 2012, declining to 4.5 percent by 2022 as the industry achieves larger-scale operations. On this basis, total R&D spending is estimated to rise to $0.7 billion in 2016, reaching $1.8 billion by 2022. Employment in advanced biofuels R&D is estimated to reach 4,800 by 2016 rising to 12,100 by 2022.

Technology royalties. U.S. companies at the forefront of developing and commercializing advanced biofuels production technologies will likely have opportunities to leverage their intellectual property assets by licensing technology to partners outside the United States or by building and operating advanced biofuels operations in other countries. We estimate the value of potential technology royalties as summarized in Table 3. The International Energy Agency's World Energy Outlook calls for 52 BGY of advanced biofuels globally by 2030 in its Alternative Policy case. Here, we assume that global advanced biofuels production will rise to 33 BGY by 2022, with 12 BGY of advanced biofuels production outside the United States. We assume royalty payments of $0.06 per gallon are paid for one-third of advanced biofuels produced outside the United States. This results in royalties of $240 million to U.S. companies by 2022.

Table 3: Value of Advanced Biofuels Technology Royalties from Production Outside the U.S.

Year	US advanced biofuels production	Non-US advanced biofuels production	Share of non-US production under US license	Royalty ($/gallon)	Royalty value (billion $)
2009	0.6				
2010	1.0				
2011	1.4				
2012	2.0	0.2	0.33	$0.06	$0.0
2013	2.8	1.4	0.33	$0.06	$0.0
2014	3.8	2.6	0.33	$0.06	$0.1
2015	5.5	3.7	0.33	$0.06	$0.1
2016	7.3	4.9	0.33	$0.06	$0.1
2017	9.0	6.1	0.33	$0.06	$0.1
2018	11.0	7.3	0.33	$0.06	$0.1
2019	13.0	8.5	0.33	$0.06	$0.2
2020	15.0	9.6	0.33	$0.06	$0.2
2021	18.0	10.8	0.33	$0.06	$0.2
2022	21.0	12.0	0.33	$0.06	$0.2

Measuring Total Economic Impact

The total economic impact of advanced biofuels production will be the combination of direct, indirect, and induced output effects in the economy (Figure 5).

- **Direct output** is a measure of the value of goods and services that can be directly attributed to the sector.
- **Indirect output** accounts for the changes in activity in other sectors as a result of increased demand from the directly affected sector.
- **Induced output** reflects the impact of increased consumer spending resulting from income changes in the directly and indirectly affected sectors.

We estimate indirect and induced economic output and job creation using multipliers derived from a review of detailed economic input-output models of biofuels plants (see Appendix). Table 4 summarizes the multipliers used in this analysis for U.S. economic impacts from various measures of direct economic activity in advanced biofuels production.

Output multipliers		Jobs multipliers	
Construction	3.2	Construction	2.3
Operations	3.4	Operations	5.3
Feedstocks	3.4	Feedstocks	5.3
Distribution	3.4	Distribution	5.3

Table 4: U.S. Economic Multipliers for Advanced Biofuels

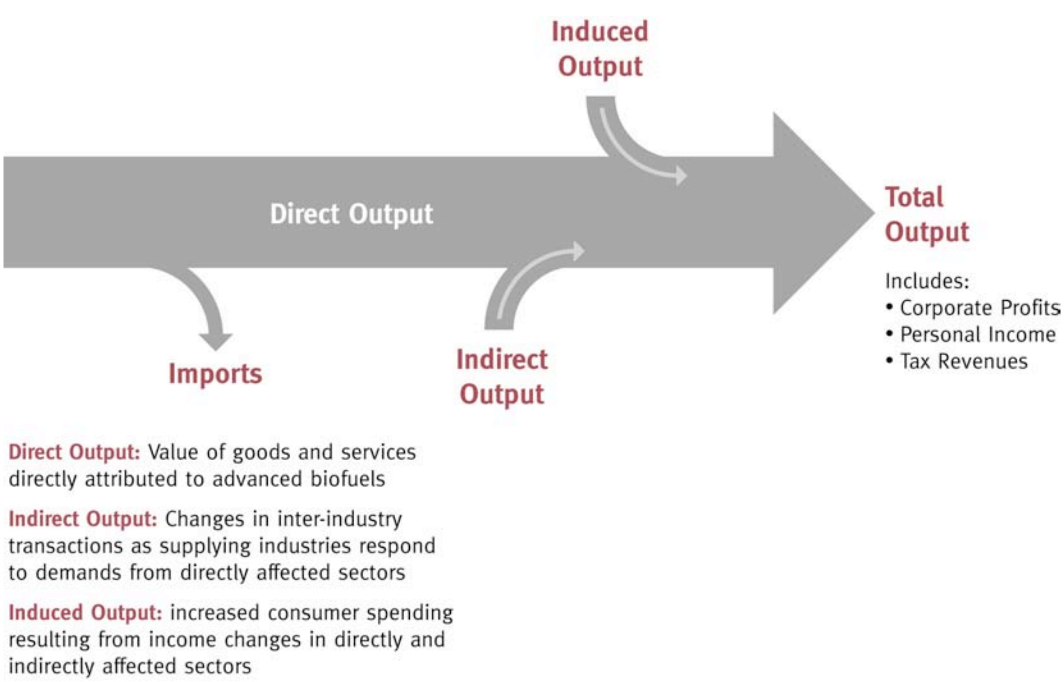


Figure 5: Measuring Economic Output from Advanced Biofuels Production: Direct, Indirect, and Induced Output

Economic Output from Advanced Biofuels Production

Total direct economic impacts for the RFS scenario are summarized in Figure 6. We estimate a total direct economic impact that rises to $9.3 billion by 2012 and $49.6 billion by 2022. Applying the appropriate economic multipliers to each category of direct output yields a total economic output impact that rises to $20.2 billion in 2012 and approximately $150 billion in 2022 (Figure 7).

Figure 6: Direct Economic Output from U.S. Advanced Biofuels Production

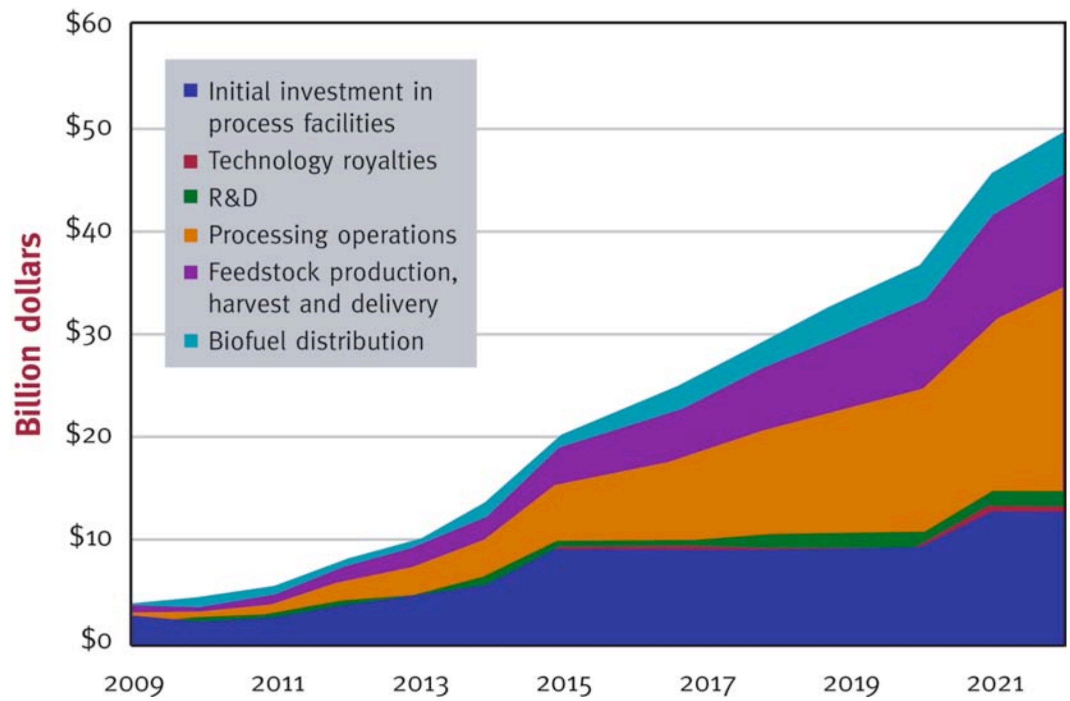
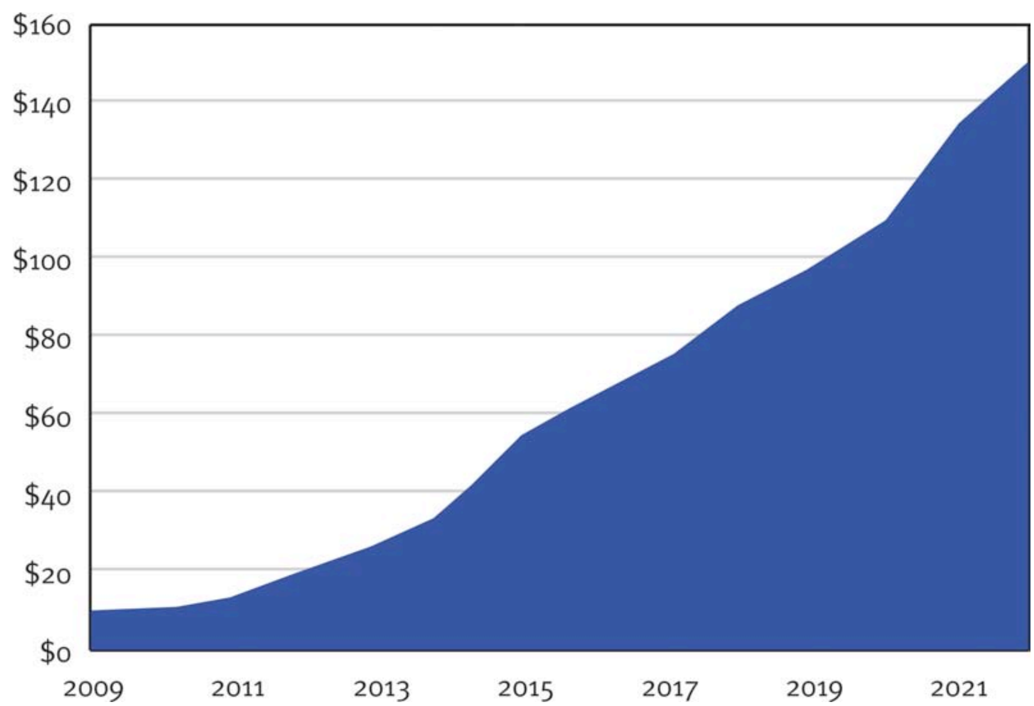


Figure 7: Total Economic Output from U.S. Advanced Biofuels Production



Job Creation

Figure 8 summarizes estimated job creation under the RFS scenario. The total number of jobs directly created reaches 29,000 by 2012 and 190,000 by 2022. Taking into consideration indirect job creation as a result of the economic stimulus created by biofuels development brings total job creation to 123,000 by 2012 and 807,000 by 2022 (Figure 9). These estimates assume that only half of new jobs created in biofuels transportation and distribution represent net job creation in the U.S. economy, since some offsetting jobs losses in the petroleum industry will occur as a result of biofuels' displacement of petroleum product volumes.

Construction jobs will be temporary and are not accumulated as permanent job creation is this analysis. Construction jobs are estimated based on annual construction requirements for each year in the study period. Moreover, the jobs multiplier for construction jobs is less than half that for other permanent jobs created in advanced biofuels operations.

Of the total number of direct jobs created, 46 percent are in the feedstock production (primarily agriculture) and 35 percent are in construction, engineering and procurement, including both on-site and off-site activities.

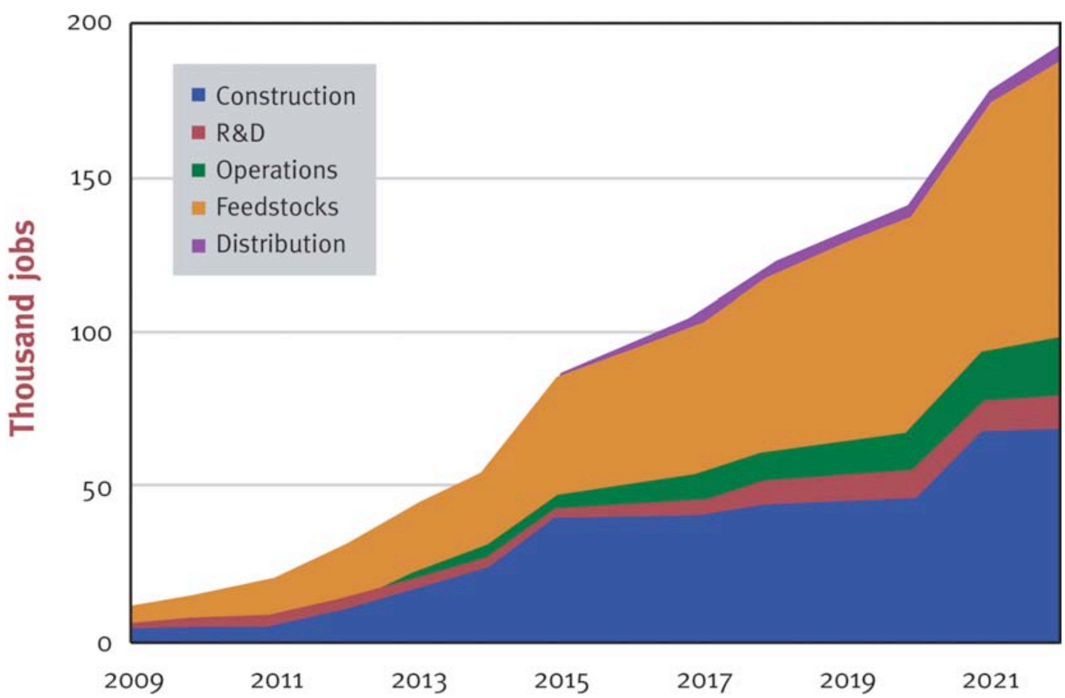
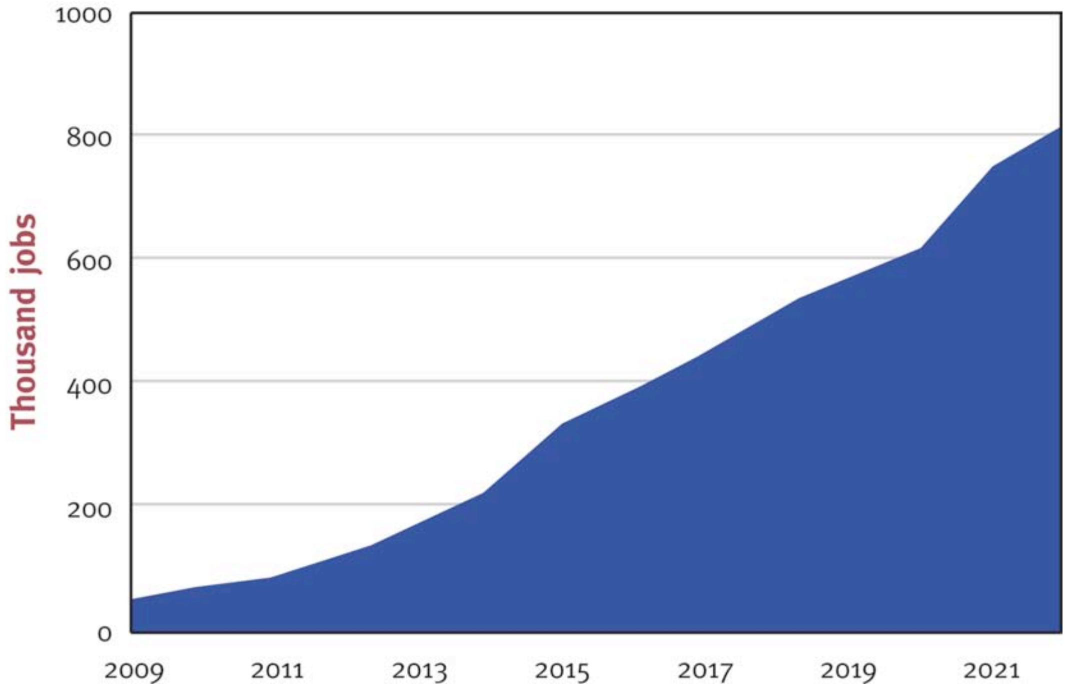


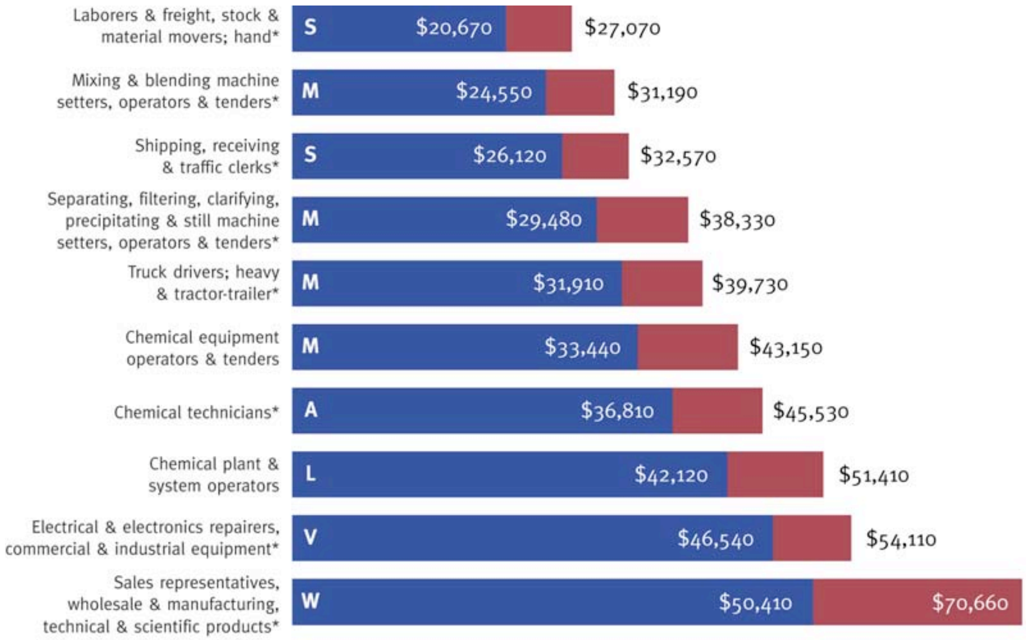
Figure 8: Jobs Directly Created from U.S. Advanced Biofuels Production

Figure 9: Total Jobs Created from U.S. Advanced Biofuels Production: Direct, Indirect, and Induced



The types of jobs likely to be created in advanced biofuels processing facilities are described in Figure 10. These represent middle-skill occupations in the basic chemical manufacturing industry, which includes today's corn-based ethanol and biodiesel production operations. Median annual wages for these jobs range from $27,000 to $71,000, depending on skill levels. As the advanced biofuels industry matures, specialized training and skill certification paths are likely to develop for jobs in biofuels processing operations.

Figure 10: Biofuels Jobs: Wages and Skills



Notes

This chart depicts national wage data for selected middle-skill occupations in the basic chemical manufacturing industry, which includes ethanol and biodiesel production

- The 25th percentile describes wages at the lower end of the labor market.
- Median wage marks the center of the wage distribution in a given occupation.

* In-Demand occupation per DOL, regardless of overall occupational growth levels, because the work is central to a high-growth industry, like energy or construction.

Regional wage ranges and more precise occupational projections by industry can be run on a state-by-state basis.

Typical education and training path:

S Short-term on-the-job training: Requires no more than a month of workplace-based training.
M Moderate-term on-the-job training: Requires from one to twelve months of training, which typically occurs at the workplace.
L Long-term on-the-job training: Requires more than one year of on-the-job training, or combined work experience and classroom instruction, and may include apprenticeships of up to five years.
V Postsecondary vocational award: Requires credentials earned in training programs lasting from a few weeks to more than a year, typically offered at vocational or technical schools.
A Associate degree: Requires two years of full-time academic work beyond high school.
W Work experience in related occupation.

These are general indicators; there may be other pathways into the occupation, as well as additional educational, training, or licensing requirements.

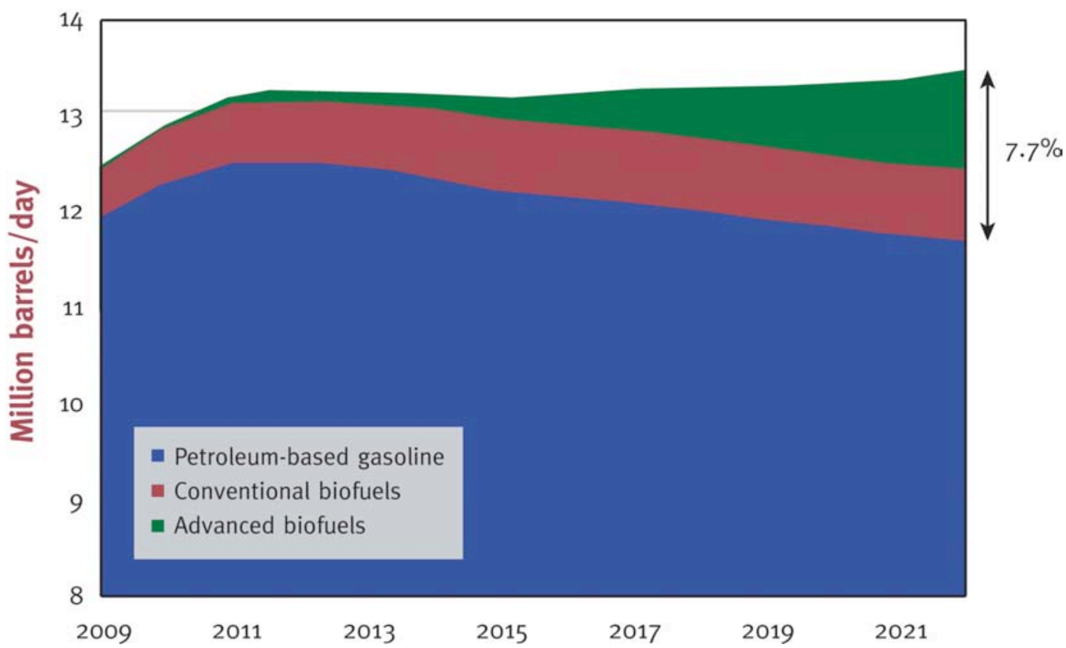
Source: U.S. Bureau of Labor Statistics; Greener Pathways: Jobs and Workforce Development in the Clean Energy Economy (2008)

Balance of Trade and Oil Import Dependence

How will meeting the RFS levels for advanced biofuels production affect the U.S. balance of trade and oil import dependence? Producing 21 billion gallons of advanced biofuels by 2022 would displace at least 15 billion gallons of gasoline and diesel fuel.* This represents 7.7 percent of projected U.S. gasoline and diesel consumption in 2022.

U.S. advanced biofuels production under the RFS scenario will reduce the need for petroleum imports by approximately $5.5 billion in 2012, $23 billion in 2016, and nearly $70 billion by 2022.** The cumulative total of avoided petroleum imports over the period from 2010 to 2022 exceeds $350 billion. These estimates represent a conservative minimum impact, since they do not take into consideration the impact of reduced U.S. oil imports on world oil prices. The increase in production of advanced biofuels under the RFS would actually result in an absolute reduction in U.S. gasoline and diesel consumption between 2011 and 2022.

Figure 11: Biofuels Contribute a Growing Share of U.S. Transportation Fuel Supplies



** The exact amount will depend on the average energy content of the portfolio of biofuels produced. Advances in automotive technology are likely to yield improvements in the performance of ethanol-fueled vehicles. In Sweden, GM/Saab produces a car with a high-compression engine that gets 95% as much mileage from a gallon of ethanol as it does from a gallon of gasoline. We assume that the gasoline displacement ratio for biofuels will rise from 70% in 2009 to 75% by 2022 as a result of a combination of changes in biofuel products and improving engine technologies.*

*** Based on projected petroleum product values in the U.S. Energy Information Administration's Annual Energy Outlook 2009.*

45 BGY of Advanced Biofuels by 2030: Economic and Job Implications

Under the RFS, the U.S. will add 3 BGY of advanced biofuels production each year from 2020 to 2022. If capacity additions were to continue at this same rate through 2030, advanced biofuels production capacity would reach 45 BGY, bringing total U.S. biofuels production to 60 BGY, assuming conventional biofuels production capacity remains flat at 15 BGY. Altogether, this would displace about 22 percent of projected U.S. gasoline consumption in 2030.

Bio-era analyzed the implications of a 45 BGY scenario for advanced biofuels production in terms of economic output and job creation, using the same economic model developed to assess advanced biofuels production under the RFS. Key assumptions through 2030 are as follows:

- Biomass feedstocks come from a portfolio of sources, including energy crops and agricultural and forest residues (see Figure 12). Total biomass utilization reaches 470 million tons in 2030.
- Due to learning curve effects, capital costs for advanced biofuels processing plants fall 5 percent between 2022 and 2030 to an average $3.44 per gallon annual production capacity.
- Biofuels transportation and distribution costs continue to fall as volumes increase, declining to an average of $0.20 per gallon by 2030.
- Streamlining of operations at biofuels processing plants reduces the number of jobs to 85 employees at a typical 100 million gallon advanced biofuels processing plant, including inbound and outbound materials handling, plant operations, and management.
- Operating costs fall to $1.45 per gallon by 2030, bringing total biofuel production costs to approximately $1.88 per gallon.

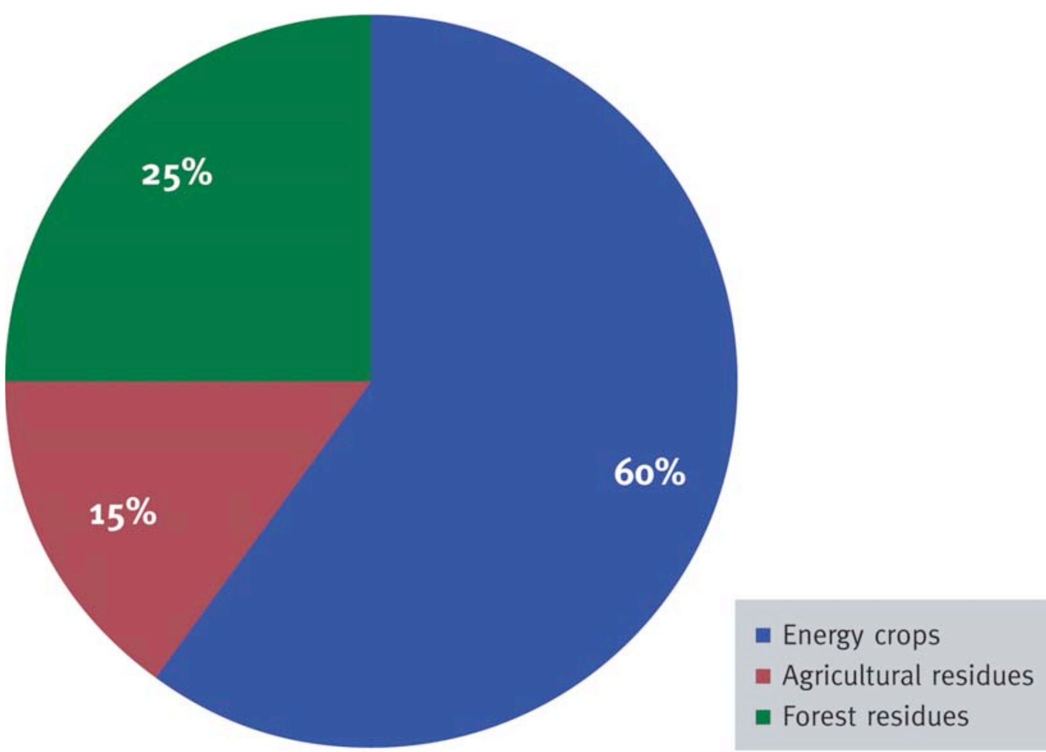


Figure 12: Biomass Feedstocks for 45 BGY Advanced Biofuels Production

Based on these assumptions, producing 45 billion gallons of advanced biofuels in 2030 would result in direct economic output of $113 billion. Taking into consideration multiplier effects in the economy, the total U.S. economic output effect, including indirect and induced economic output, is $300 billion (see Figure 13 and Table 5).

Figure 13: Direct Economic Output from 45 BGY Advanced Biofuels Production (billion dollars)

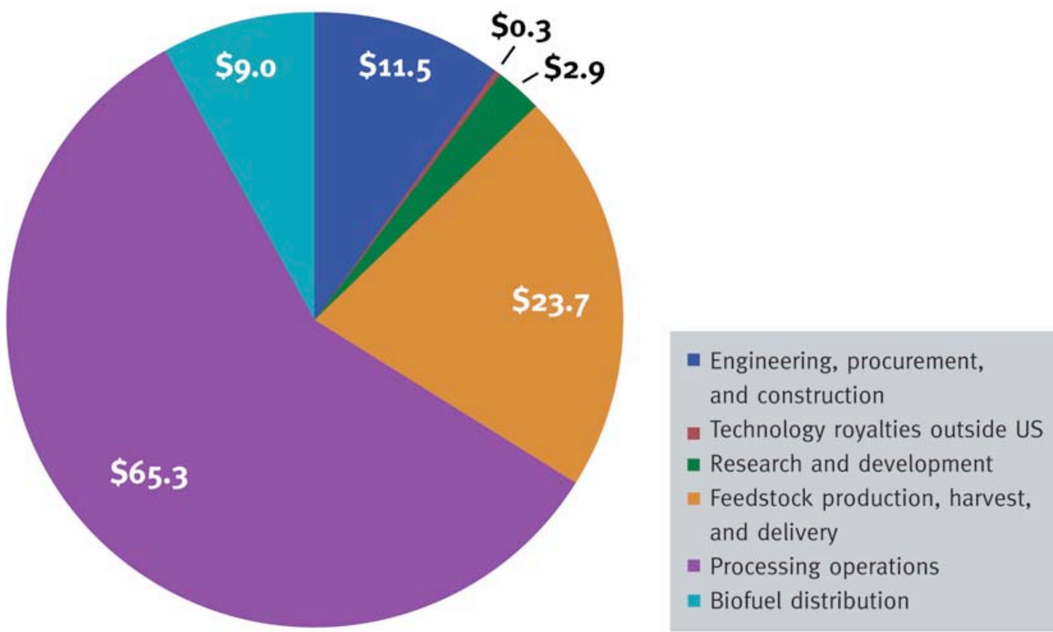


Table 5: Economic Output Effect of 45 BGY Advanced Biofuels Production

Engineering, procurement, and construction	$11.5	10.2%
Technology royalties outside US	$0.3	0.3%
R&D	$2.9	2.6%
Feedstock production, harvest and delivery	$23.7	21.0%
Processing operations	$65.3	57.9%
Biofuel distribution	$9.0	8.0%
Total direct output	**$112.6**	
Total output with multiplier effects	**$299.6**	

Direct job creation is 393,000 jobs, with a total employment impact of 1.9 million jobs created directly or indirectly in the U.S. economy (see Figure 14 and Table 6). Nearly 70 percent of these jobs are in areas related to feedstock production, harvesting, and transport, providing valued jobs and income creation in rural areas. Other high-value jobs are created in areas of research and development, engineering, procurement and construction, and processing operations.

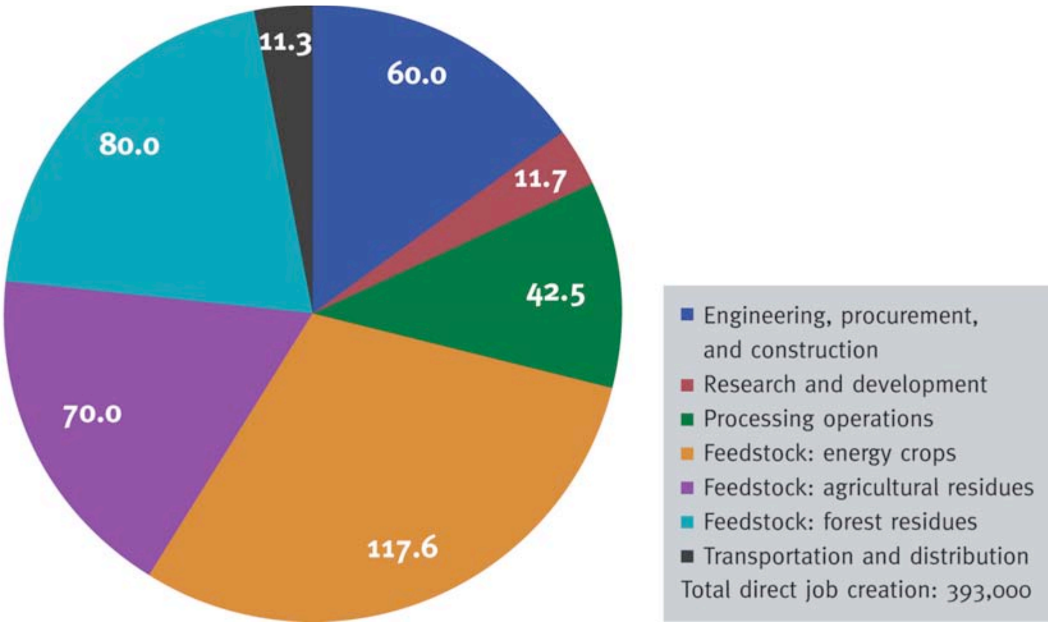


Figure 14: **Direct Job Creation from 45 BGY Advanced Biofuels Production**

Table 6: **Direct Job Creation from 45 BGY Advanced Biofuels Production (new jobs created)**

Engineering, procurement, and construction	60.0	15.3%
R&D	11.7	3.0%
Direct processing	42.5	10.8%
Feedstock supply:	267.6	68.0%
Energy crops	117.6	29.9%
Agricultural residues	70.0	17.8%
Forest residues	80.0	20.3%
Transportation and distribution	11.3	2.9%
Direct new jobs created	**393.1**	**100.0%**
Total new jobs (direct, indirect, and induced)	**1,903,400**	

Conclusion

The build-out of a new advanced biofuels industry to meet the requirements of the Renewable Fuel Standard through 2022 will entail the development and commercialization of new technology, the investment of nearly $95 billion in new processing plants, and the direct creation of nearly 200,000 new jobs. In addition, the growth of this new industry will reduce the nation's dependence on imported oil, potentially reducing oil imports by as much as $70 billion per year by 2022. Finally, the growth of the advanced biofuels industry will provide stimulus to the ongoing development of advanced biotechnology tools and platforms for production of energy, chemicals, and materials.

Achieving advanced biofuels production of 45 billion gallons by 2030 would bring even greater economic and employment benefits. Together with the anticipated 15 billion gallons of conventional biofuels production capacity, this would bring total U.S. biofuels production to 60 billion gallons, enough to supply 22 percent of projected U.S. gasoline consumption. Total job creation in this scenario, including indirect and induced jobs, reaches nearly 1.4 million jobs by 2030.

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Notes

[1] For further information on these studies, see list of Sources provided in this report.

[2] See, for example, Biomass Research and Development Initiative, Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications, and the Role of Research, 2008.

[3] This figure includes not only farm workers, but labor required for all other feedstock production-related activities. Hence, it is slightly higher than conventional estimates of farm-level employment.

[4] Eidman, Vernon R., "Economic Parameters for Corn Ethanol and Biodiesel Production," Journal of Agricultural and Applied Economics, August 2007,

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Appendix: Methodology for Economic Impact Analysis

Base Assumptions

This analysis compares the economic and job impacts of producing advanced biofuels at levels required in the Renewable Fuels Standard (RFS) with an alternative case in which there is no advanced biofuels production.

- **Advanced Biofuels RFS.** In this case, advanced biofuels are produced in the United States in accord with levels specified in the Energy Independence and Security Act (EISA) of 2007 (Table A1). For these purposes, "advanced biofuels" includes cellulosic ethanol, biomass-based biodiesel, and other unspecified types of biofuels other than conventional corn-based ethanol and vegetable oil-based biodiesel. In this scenario, advanced biofuels production reaches 21 billion gallons per year in 2022.

- **No Advanced Biofuels.** In this case, there is no commercial production of advanced biofuels in the U.S.

The EISA offers the following definitions for the biofuels categories described in the Act:

- **Conventional biofuel** means ethanol derived from corn starch. Those facilities that commence construction after the date of enactment must achieve at least a 20 percent reduction in lifecycle greenhouse gas emissions compared to baseline lifecycle greenhouse gas emissions.

- **Advanced biofuel** means renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions that achieve at least a 50 percent reduction over baseline lifecycle greenhouse gas emissions. The types of fuels eligible for consideration as "advanced biofuel" may include: ethanol derived from cellulose or lignin, sugar or starch (other than corn starch), or waste material, including crop residue, other vegetative waste material, animal waste, and food waste and yard waste; biomass-based diesel; biogas produced through the conversion of organic matter from renewable biomass; butanol or other alcohols produced through the conversion of organic matter from renewable biomass; and other fuel derived from cellulosic biomass.

- **Cellulosic biofuel** means renewable fuel derived from any cellulose or lignin that is derived from renewable biomass and that has lifecycle greenhouse gas emissions that achieve at least a 60 percent reduction over baseline lifecycle greenhouse gas emissions.

- **Biomass-based diesel** means renewable fuel that is biodiesel as defined in section 312(f) of the Energy Policy Act of 1992 and that has lifecycle greenhouse gas emissions that achieve at least a 50 percent reduction over baseline lifecycle greenhouse gas emissions. Biomass-based diesel is included as a component of Advanced Biofuels.

Table A1: Renewable Fuel Standard: Energy Independence and Security Act of 2007

Year	Conventional Biofuel	Total Advanced Biofuel	Cellulosic Biofuel	Biomass-based Diesel	Unspecified Advanced Biofuel	Total Renewable Fuel Standard
2008	9.0					9.0
2009	10.5	0.6		0.5	0.1	11.1
2010	12.0	1.0	0.1	0.7	0.2	13.0
2011	12.6	1.4	0.3	0.8	0.3	14.0
2012	13.2	2.0	0.5	1.0*	0.5	15.2
2013	13.8	2.8	1.0	1.0*	0.8	16.6
2014	14.4	3.8	1.8	1.0*	1.0	18.2
2015	15.0	5.5	3.0	1.0*	1.5	20.5
2016	15.0	7.3	4.3	1.0*	2.0	22.3
2017	15.0	9.0	5.5	1.0*	2.5	24.0
2018	15.0	11.0	7.0	1.0*	3.0	26.0
2019	15.0	13.0	8.5	1.0*	3.5	28.0
2020	15.0	15.0	10.5	1.0*	3.5	30.0
2021	15.0	18.0	13.5	1.0*	3.5	33.0
2022	15.0	21.0	16.0	1.0*	4.0	36.0

**Minimum 1 BGY. Specific amount to be determined by the EPA Administrator.*

Economic Impact Analysis

To assess the probable direct economic implications of biofuels production, we reviewed published literature and industry estimates describing the likely size, cost, and labor requirements for advanced biofuels production facilities. These estimates are necessarily speculative, given that the industry is still in a period of rapid technology development. Actual operating experience is confined to pilot or pre-commercial facilities.

Nevertheless, numerous publicly available studies provide detailed estimates of key parameters for advanced biofuels plants based on engineering analyses and assumptions about possible configurations of conversion technologies. Here, we summarize the basis for our assumptions about various parameters for advanced biofuels production facilities.

Processing plant construction costs. Table A2 summarizes published capital cost estimates for cellulosic ethanol plants. Most of these estimates are based on engineering analyses using conventional conversion technologies. Several emerging companies claim to be developing technologies with lower capital costs than those reflected in the academic studies summarized in Table A2. We assume capital costs for advanced biofuels plants will fall in the range of \$5.00–5.50 per gallon of annual production capacity in 2009, falling to \$3.50–4.00 per gallon in 2022 (Table A3).

Table A2: Capital Cost Estimates for Cellulosic Ethanol Processing Facilities

	Construction cost estimates	Comments
Perez-Verdin (2008)	$4.31	52 MGY cellulosic ethanol plant using woody biomass
DeVos (2007)	$4.00	50 MGY cellulosic ethanol plant
Liestritz (2007)	$3.53	50 MGY cellulosic ethanol plant using wheat straw
Flanders (2007)	$4.59	49 MGY cellulosic ethanol plant (Range Fuels)
Aden (2002)	$2.11	NREL study; cellulosic ethanol plant crop waste or switchgrass
BBI (2002)	$2.11	32.4 MGY cellulosic ethanol plant using wood residues
Wright (2007)	$5.05	50 MGY cellulosic ethanol plant

Table A3: Assumed Capital Cost for New Advanced Biofuels Production Plants (dollars per gallon annual production capacity)

Year	Plant capacity (MGY)			
	20	50	100	200
2009	$5.50	$5.25	$5.00	
2010	$5.38	$5.13	$4.88	
2011	$5.27	$5.02	$4.77	
2012	$5.15	$4.90	$4.65	
2013	$5.04	$4.79	$4.54	$4.50
2014	$4.92	$4.67	$4.42	$4.39
2015	$4.81	$4.56	$4.31	$4.28
2016	$4.69	$4.44	$4.19	$4.17
2017	$4.58	$4.33	$4.08	$4.06
2018	$4.46	$4.21	$3.96	$3.94
2019	$4.35	$4.10	$3.85	$3.83
2020	$4.23	$3.98	$3.73	$3.72
2021	$4.12	$3.87	$3.62	$3.61
2022	$4.00	$3.75	$3.50	$3.50

Biomass-based biodiesel production. Table A4 summarizes key assumptions regarding costs of biomass-based biodiesel production.

Year	Initial investment per gallon	Processing costs per gallon
2009	$4.00	$1.60
2010	$3.96	$1.59
2011	$3.92	$1.58
2012	$3.88	$1.58
2013	$3.85	$1.57
2014	$3.81	$1.56
2015	$3.77	$1.55
2016	$3.73	$1.55
2017	$3.69	$1.54
2018	$3.65	$1.53
2019	$3.62	$1.52
2020	$3.58	$1.52
2021	$3.54	$1.51
2022	$3.50	$1.50

Table A4: Biomass-based Biodiesel Plants

Construction jobs. Table A5 summarizes estimates of the number of jobs created to construct advanced biofuels facilities. Because these jobs are temporary, estimates are provided as full-time equivalents (FTE). We assume an industry average of 20 FTE per gallon of annual production capacity. These jobs include not just on-site construction, but all engineering, procurement, permitting, legal, management, and other construction-related employment as well as off-site employment in construction of equipment deployed in the facility.

Solomon (2007) Scenario B	40.5
Solomon (2007) Scenario C	32.9
MA ABTF (2008)	22.5
Leistritz (2007)	15.9
Flanders (2007)	6.4

Table A5: Direct Construction Jobs Created in Advanced Biofuels Plant Construction (FTE per million gallons annual production capacity)

Operations costs. Estimates of operating costs for advanced biofuels plants, including feedstock costs are summarized in Table A6. In addition to feedstock supply, operating costs include energy and utilities, maintenance, and operating staff. We assume average operating costs of $1.65 per gallon in 2009, falling to $1.47 in 2022 as industry learning curve effects lead to cost reductions.

TABLE A6: Estimated Operating Costs for Advanced Biomass Production

Liestritz (2007)	$1.49	Includes feedstock costs of $1.06 for $40/t wheatstraw
MA ABTF (2008)	$2.36	Includes $1.88 in feedstock costs
Wright (2007)	$1.76	Includes $1.03 in feedstock costs

Operations Jobs. The number of full-time jobs required to support operation of advanced biofuels plants is expected to be higher than that required for existing corn ethanol plants. Table A7 summarizes the estimated full-time job requirements of various types of biofuels plants, including corn ethanol plants, according to recent studies. We assume an average of 0.9 jobs per million gallons of annual production capacity or, for example, 90 jobs for a 100 million gallon per year plant. While the number of jobs per gallon of capacity is likely to decline with the size of the plant, we assume 0.9 jobs as an average across all plant sizes.

TABLE A7: Jobs in Advanced Biofuels Processing Plants (FTE per million gallons annual capacity)

Solomon (2007) Scenario B	17.1	Cellulosic ethanol plant processing wood waste and switchgrass, jobs estimate includes feedstock supply
Solomon (2007) Scenario C	10.5	
Perez-Verdin (2008)	17.5	52 MGY cellulosic ethanol plant using woody biomass; includes feedstock production and delivery jobs
Liestritz (2007)	1.5	50 MGY cellulosic ethanol plant using wheat straw
MA ABTF	1.8	Average for advanced biodiesel plants
Hodur (2006)	0.8	Corn ethanol
Urbanchuk (2007)	4.0	Biodiesel
Petersan (2002)	0.6	Corn ethanol
Schlosser (2008)	1.1	80 MGY corn ethanol plant
Aden (2002)	1.1	NREL study; cellulosic ethanol using plant crop waste or switchgrass
Swenson (2007)	0.46	Corn ethanol

Indirect and Induced Output Effects

The total economic impact of advanced biofuels production will be the combination of direct, indirect, and induced output effects on the economy (see Figure A1).

- **Direct output** is a measure of the value of goods and services that can be directly attributed to the sector
- **Indirect output** accounts for the changes in activity in other sectors as a result of increased demand from the directly affected sector
- **Induced output** reflects the impact of increased consumer spending resulting from income changes in the directly and indirectly affected sectors.

For this study, estimates of the direct effects of advanced biofuels production for the U.S. economy are built up from plant-by-plant figures for expenditures, including construction, operations, and feedstock supply. In addition, revenues earned from licensing advanced biofuels production technologies developed in the United States are estimated. Finally, costs of biofuels transportation and distribution are derived based on overall production volumes.

Indirect and induced effects are estimated based on multiplier effects for the U.S. economy. The multiplier represents the total economic effect, including indirect and induced effects, divided by the direct effect. The multipliers for economic output and jobs used in this study were developed based on a meta-analysis of detailed input-output studies that analyze the impacts of biofuels projects summarized in Table A8. The main economic models used to trace interindustry transactions and thereby assess indirect and induced economic effects include RIMS II, IMPLAN, and REMI's Policy Insight.

To apply these models, users must categorize various commodity and services input requirements for the construction and operation of a facility. The multiplier values for each category, derived from the input-output (I-O) model, are then applied to yield an overall multiplier value.

Numerous studies have been undertaken using the IMPLAN, RIMS II, and Policy Insight models to assess the total economic impact of biofuels plants, including both conventional and advanced biofuels technologies. For example, Schlosser (2008), Pierce (2007), and Swenson (2007) used I-O models to assess the economic impacts, measured in terms of economic impacts and job creation, of corn-based ethanol production facilities.

Perez-Verdin (2008), Leistritz (2008), and Solomon (2008) used these methods to evaluate the economic impact of lignocellulosic ethanol production facilities and energy crop production at local, state, or regional levels. Similarly, the Massachusetts Advanced Biotechnology Task Force (2008) used multipliers derived from IMPLAN to estimate the economic and employment impacts of a scenario for advanced biofuels production in the state of Massachusetts. In general, the more narrowly limited the scope of impact analysis—for example, county or state impacts versus regional or national—the smaller multipliers will be. This is because part of the economic impact is felt outside the region of study. Input-Output models can be used to estimate the amount of "leakage" from the economic region being studied.

For the purposes of this study, national economic impacts are the point of focus. Nonetheless, the many studies of local and regional economic impacts of biofuels plants provide useful context for estimating the likely multiplier effects of advanced biofuels plants at the national level. For example, the breakdown of expenditures by category for lignocellulosic biofuels facilities is substantially similar to that for other types of biofuels plants. Moreover, the recent studies that have focused specifically on lignocellulosic ethanol production provide a foundation for estimating the probable range of multipliers for advanced biofuels development. Higher-level analyses, for example Dale (2006), have used estimated multiplier effects for the U.S. economy in estimating the aggregate economic impact of various scenarios for biofuels development.

Economic output. Table A8 summarizes the multipliers derived from the application of IMPLAN and other I-O models in evaluating specific biofuels projects. While the majority of these analyses measure state-level impacts, Ugarte (2006) used POLYSIS and IMPLAN models to measure the impacts on the national economy of advanced biofuels production. Ugarte analyzed impacts of cellulosic ethanol production from corn stover, rice straw, wheat straw, and/or switchgrass drawing on technical and economic analysis of emerging biorefinery technologies performed by the National Renewable Energy Laboratories (NREL). Ugarte's research yielded a multiplier of 3.4 for annual output from biofuels production operations. We assume a U.S. economic output multiplier of 3.4, consistent with Ugarte's results.

Table A8: Input-Output Model Results for Economic Output Multipliers based on Annual Output from Biofuels Production Operations

MA ABTF (2008)	1.9	State-level analysis applying IMPLAN multipliers to advanced biofuels production scenarios for Massachusetts
Swenson (2007)	1.7	Adjusted IMPLAN analysis of U.S. impact with downward adjustments to multipliers particular to corn ethanol
Leistritz (2007)	3.5	North Dakota I-O Model cellulosic ethanol production; in-state share of initial plant construction assumed to be 15 percent
Perez-Verdin (2008)	1.6	IMPLAN analysis of woody biomass-based biofuels production for Mississippi
Flanders (2007)	1.6	IMPLAN analysis of cellulosic ethanol production in Georgia
Ugarte (2006)	3.4	POLYSYS/IMPLAN analysis of impacts on national economy of advanced biofuels production
Pierce (2007)	1.9	IMPLAN analysis of corn ethanol production in Missouri

Construction output. The dollars spent on construction of biofuels plants have significantly different sectoral allocations than those flowing from ongoing biofuels production. Moreover, the transitory nature of construction activity yields different economic consequences. Table A9 summarizes multipliers estimated in studies that assessed multipliers for construction expenditures. We assume a U.S. multiplier of 2.4 for construction expenditures.

Table A9: Construction Output Multipliers for Biofuels Plant Construction

MA ABTF (2008)	2.4	Construction multiplier for Massachusetts economy, advanced biofuels construction
Dale (2006)	2.4	Estimate of U.S. multiplier for construction of cellulosic ethanol plants derived from multipliers for construction of corn ethanol plants
Flanders (2007)	1.7	IMPLAN analysis of multiplier for Georgia for cellulosic ethanol plant construction

Permanent jobs. Previous studies have yielded permanent jobs multipliers ranging from 2.3 to 6.4 for biofuels production operations (Table A10). Even higher multipliers (Leistritz, Pierce) result from calculating the total number of direct, indirect, and induced jobs created, including agricultural jobs in feedstock production, divided by the number of direct jobs in biofuels manufacturing. For our analysis, we estimate direct jobs created in biofuels production, agricultural production, and biofuels distribution and apply multipliers to each of these in order to estimate total U.S. job creation impacts.

Table A10: Permanent Jobs Multipliers from Biofuels Production

MA ABTF (2008)	2.3	Massachusetts multiplier based on “high level” analysis of multipliers from IMPLAN models
Swenson (2007)	5.3	U.S. permanent jobs multiplier based on adapted IMPLAN model of organic chemicals sector
Leistritz (2007)	28.8	Total jobs multiplier (including agricultural jobs created) from biofuels production derived from North Dakota Input Output Model
Flanders (2007)	2.8	
Flanders (2007)	6.4	
Schlosser (2008)	3.8	Permanent jobs multiplier for 80 MGY corn ethanol plant
USDA (2008)	6.3	
Ugarte (2006)	3.4	U.S. jobs multiplier for cellulosic ethanol production
Pollin (2008)	2.1	Estimated average multiplier for several categories of “green jobs” including biofuels production
Swenson (2008)	3.7	Permanent jobs multiplier for Iowa based on corn ethanol production
Pierce (2007)	21.6	Jobs multiplier for corm ethanol in Missouri

Construction jobs. Results of previous studies of multipliers from construction jobs related to biofuels plants are summarized in Table A11. Jobs multipliers for construction are typically lower than those for permanent jobs. While neither of the studies cited estimates national jobs multipliers, we conservatively assume a U.S. jobs multiplier for biofuels plant construction of 2.3.

Table A11: Multipliers for Construction Jobs in Biofuels Plant Construction

MA ABTF (2008)	2.3	Massachusetts multiplier based on “high level” analysis of multipliers from IMPLAN models
Flanders (2007)	1.6	Jobs multiplier for Georgia based on IMPLAN model results

California Dairy Campaign

The Honorable Fred Upton
Chairman
The Honorable Henry Waxman
Ranking Member
Committee on Energy and Commerce
U.S. House of Representatives
RFS@mail.house.gov

Dear Rep. Upton and Waxman:

The California Dairy Campaign (CDC) respectfully submits comments to the questions for stakeholders relating to the renewable fuels standard (RFS) mandate. The California Dairy Campaign (CDC) is a grassroots organization of dairy farmers who are working to encourage lawmakers and the dairy industry to be more responsive to the needs of the family dairy farm in California. CDC is a member organization of California Farmers Union.

Questions for Stakeholder Comment

1. The RFS has created an artificial mandate for use of corn in ethanol production which has caused commodity prices to increase across the board. The unprecedented rise in feed costs has led many dairies in our state to close their doors and has pushed many more dairy operations near the brink of closure.

2. In 2012 alone, 105 dairies went out of business which is a record number. The closures were due to a number of factors, but the unprecedented rise in feed causes driven largely by the ethanol mandate is a major contributor to the serious financial decline of our state's dairy operations. Record feed prices caused by the usage of more than 40 percent of the corn crop in ethanol production has led to an incredible rise in input costs that is pushing dairies across California near the brink of financial ruin.

3. Given the adverse impact that the RFS mandate is having on dairy and livestock producers and other sectors of the agricultural and food economy we do not agree with EPA's decision to deny the RFS waiver.

4. The Clean Air Act does not provide EPA sufficient flexibility to adequately address the adverse effects that the RFS has had and will continue to have on corn prices. The evidence is clear given the unprecedented and unsustainable rise in corn and other feed prices.

5. Under our current pricing system, dairy producers are not able to pass on higher feed prices and as a result many are closing their doors in our state.

We appreciate the opportunity to provide comments in the discussion and debate of the RFS mandate.

Sincerely,

Joe Augusto
President

325 Mitchell Avenue Turlock, CA 95380 (209)632-0381 Fax: (209)632-5262
P.O. Box 1957, Turlock, CA 95381 email:lmcb44@comsast.net
www.californiadairycampaign.com

Congressmen Harper and members of the House Committee on Energy and Commerce,

I respectfully provide the attached paper as my comments to the RFS questions you have posed. The issue of biofuels must be dealt with holistically because it is at the intersection of energy, food, water, land, human rights, and national security. It is the aspect of national security and national energy strategy which has motivated my research on this topic and the publication of two papers. I have found that even asking the right questions, let alone crafting thoughtful policy, requires cross-functional expertise in the agricultural and physical sciences. The attached paper makes a holistic case against biofuels based on physics, chemistry, biology, economics, and history. It's conclusions and policy recommendations in Section 14 are supported by 9,000 words of endnotes citing government agencies, US and international science academies, and peer-reviewed scientific journal articles. It shows by energy balance and energy return on investment (EROI) that cultivated crop liquid biofuels are critically dependent upon fossil fuels for the vast majority of their energy content, and are accelerating fossil fuel use rather than slowing it. The RFS has put the USA in the peculiar position today of importing biofuel from Brazil while exporting US refined gasoline overseas—neither of which promote energy security or economic security. Even after nearly 8 years of $6 billion a year subsidies, the retail price of corn ethanol today at the gas pump is still 23 cents per gallon more expensive than premium gasoline, and biodiesel is still far more expensive than petroleum diesel, and only 20,069 gallons of cellulosic ethanol have ever been sold commercially in the US.

5. What has been the impact, if any, of the RFS on food prices? For the answer from the global perspective of the UN FAO, UN Food Program, and many other international organizations who have petitioned the G20 to abandon all biofuel mandates, see Section 12 of the attached paper.

6. What role could cellulosic biofuels play in mitigating the potential effects of the RFS on corn prices? Cellulosic biofuels are non-viable due to insurmountable limitations of physics and biology. They have far worse energy balance than the barely positive 1.25:1 EROI of corn ethanol. Cello and Range Fuels imploded in scandal without ever producing a drop. Iogen (Canada) and Amyris and KL Energy/Blue Sugars/Western Biomass Energy, and Coskata and Primus Green Energy and Codexis have all given up on cellulosic fuels after spending more than a billion dollars between them. KiOR is about to go bankrupt with a quarterly burn rate of $30M and only $41M in the bank as of 31 Dec. INEOS Bio and Fiberight and Zeachem have gone silent since last October. All the above have been promising millions of gallons of cellulosic ethanol to the EPA for years.

7. What impact are cellulosic biofuels expected to have on rural economies as the production of such fuels ramps up? Production at scale is simply not going to happen, but continuing to pump in subsidy money and build new bio-refineries even as existing ones are shutting down and being auctioned off is good for the corn belt at the expense of everyone else.

8. Will the cellulosic biofuels provisions succeed in diversifying the RFS? EPA is diversifying by nonsensically calling sugarcane ethanol from Brazil an "advanced biofuel" even though it is from a food crop and imported and thus not helping the US one iota toward fuel independence

or reducing competition with food. Diversifying with cellulosic biofuels will not happen because they will never materialize in quantity. It is a boutique product costing $10-30 per gallon, and its prices rises with rising oil prices. It is not something you want to put into a gas tank and burn.

9. What is the scale of the impact of the RFS on international agricultural production and global land use changes? See Section 10 of the attached paper. Bottom line is that non-agricultural land in developed countries is too dear to be converted to agricultural use, so the land use change costs of biofuels in general and US biofuels in particular are largely exported to developing countries such as Brazil and Indonesia. Companies go abroad and either lease confiscated land and water rights in developing countries or buy feedstock grown remotely. Witness the example of Blue Sugars (FKA KL Energy) who partnered with Petrobras to bring Brazilian cane bagasse back to the US for processing, and then "sold" the cellulosic ethanol back to JV partner Petrobras at a loss last April for demonstration and publicity purposes, but still claimed RIN credits for a commercial sale (before going bankrupt).

Sincerely yours,

CAPT T. A. "Ike" Kiefer, USN
CJCS Chair, Department of Strategy, USAF Air War College
Maxwell AFB, Montgomery AL
todd.kiefer@us.af.mil
M: 601-692-6746
Resident of Meridian MS

Twenty-First Century Snake Oil

Why the United States Should Reject Biofuels as Part of a Rational National Security Energy Strategy

WATERLOO INSTITUTE for COMPLEXITY & INNOVATION

Captain T. A. 'Ike' Kiefer

WICI Occasional Paper no. 4

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Foreground: Fritz Haber, winner of 1918 Nobel Prize for discovering how to make ammonia from natural gas. Photo in the public domain.

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Author's Biography

Captain T. A. "Ike" Kiefer is a naval aviator and EA-6B pilot with 7 deployments to the PACOM and CENTCOM AORs and 21 months on the ground in Iraq. He has a Bachelor's degree in physics from the US Naval Academy and a Master's in Strategy from the US Army Command and General Staff College. He has commanded at the O-5 and O-6 level and was 2005 action officer of the year of the Joint Staff J-7 Directorate in the Pentagon. He currently teaches strategy at the US Air Force Air War College as the CJCS Chair.

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Disclaimer

Executive Summary

Biofuels are today's quintessential example of something that sounds good in theory but proves counterproductive in practice. The US Military has been funding biofuel research, buying test and demonstration quantities of biofuels, and is now funding construction of new bio-refineries with the stated objectives of helping to commercialize production, increase the domestic fuel supply, reduce dependence upon foreign oil, and reduce fuel costs associated with oil price fluctuations. The military's role is part of a larger federal government energy strategy pursued by consecutive Presidential Administrations to migrate the US economy away from fossil fuels toward domestically produced biomass-based fuels that are purported to be perpetually renewable, easier on the environment, and enhancing to national security. Current military and national energy policy and strategy need to be informed by a better understanding of the physical limitations and negative consequences of large-scale biofuels cultivation and consumption that are only now starting to receive due attention. This paper presents a physical evaluation of key characteristics of liquid transportation fuels across the domains of physics, chemistry, biology, and economics, and highlights the deficiencies that preclude biomass from becoming a primary energy source and biofuels from replacing petroleum as a national-scale transportation fuel. These factors include fatal petroleum-dependence, poor energy return on investment (EROI), low energy density, abysmal power density, huge water footprint, demonstrable food competition regardless of feedstock, increased environmental damage, promotion of land confiscation and human rights violations, and the supreme irony of increased lifecycle greenhouse gas (GHG) emissions. This paper argues that biofuels do more to harm the causes of national and global security than to help them.

Key Words: biofuel, military, energy, strategy, policy, EROI, ethanol, biodiesel, water footprint, greenhouse gas, nitrogen, ammonia, fertilizer, nitrous-oxide, carbon dioxide, photosynthesis, biodynamics, desalination, power density

Section 1: Introduction

"Good public policy however requires good scientific analytical evidence on the risks and the opportunities of different kinds of technologies and development choices."

–UN Environmental Programme[1]

About 1200 AD in the coastal region of the Andes in what is today northern Peru, the Chimu Empire faced a severe water shortage during a prolonged drought. In a flurry of public works activity that greatly stressed the royal treasury, the government embarked on a crash program to construct a 50-kilometer canal to bring water to the people. Construction was started simultaneously on several parallel routes in hopes that one of them would pay off. A great expenditure of labor was made to erect sections of aqueduct as high as 30 meters and to waterproof miles of earthen trenches with tile. However, the evidence is that this grand waterworks project never delivered water to the capital city of Chan Chan. Modern surveys of the ruins have found a fatal flaw that doomed the work—the canal route has segments that run uphill.[2]

Unfortunately, there are similarities between Chimu engineering and the current reckless pursuit of biofuels. Both were begun without a proper survey of the terrain and obstacles, both have taken approaches that attempt to defy unyielding physical laws, and both have expended prodigious resources without achieving their goals. The Chimu tried to make water run uphill in defiance of the law of gravity. The US government and military are trying to make energy run uphill in defiance of the laws of thermodynamics.

There is a set of talking points trumpeted almost daily in the press to justify biofuels as an essential part of US energy strategy. Some prominent figures and pundits argue that biofuels will increase our domestic supply of transportation fuel, end our dependence upon foreign oil, reduce military vulnerabilities on the battlefield, and generally improve national security. Biofuels are further promised to reduce fuel price volatility, reduce polluting emissions, reduce greenhouse gases, and even stimulate the economy. These arguments all fall apart under scrutiny. The promise and curse of biofuels is that they are limited by the energy that living organisms harvest from the sun. They suffer from a fatal catch-22: uncultivated biomass produces biofuel yields that are far too small, diffuse, and infrequent to displace any meaningful fraction of US primary energy needs; and boosting yields through cultivation consumes more additional energy than it adds to the biomass. Furthermore, the harvested biomass requires large amounts of additional energy to upgrade it into the compact, energy-rich, liquid hydrocarbon form that is required for compatibility with the nation's fuel infrastructure, its transportation sector, and especially its military. When the energy content of the final product biofuel is compared to all the energy that was required to make it, the trade proves to be a very poor investment, especially in consideration of other alternatives. In many cases, there is net loss of energy. When energy balance (energy output minus energy input) across the full fuel creation and combustion lifecycle is considered, cultivated liquid biofuels are revealed to be a modern-day attempt at perpetual motion that is doomed by the laws of thermodynamics and a fatal dependence upon fossil fuel energy. Biofuels' promise of energy security also proves to be an illusion as their price is more volatile and supply less assured, being subject to the economic and political vagaries of both the international energy markets and agricultural markets, as well as the whims of weather.

This paper focuses on cultivated biomass converted into liquid transportation fuel, and all references to biofuels throughout should be taken to refer to these circumstances unless specified otherwise. The overall approach is an analysis of alternatives comparing four distinct biofuels methodologies with conventional petroleum fuel to assess their relative costs and benefits. It begins by first considering what energy security means in terms of fuel quality and supply. Then it builds an analytical framework of key parameters and shows how each of the biofuel methodologies fall short. It then provides evidence that the pursuit of biofuels is doing irreversible harm to the environment, increasing greenhouse gas emissions, undermining food security, and promoting abuse of human rights. In short, this paper finds that the United States cannot achieve energy security through biofuels, and that even the attempt is ironically achieving effects contrary to "clean" and "green" environmental goals and actively threatening global security. It concludes with specific recommendations for policy and action.

Section 2: Failing to Learn the Lessons of History and Current Science

Scientists have been looking at alternatives to petroleum fuels for over a century. The first commercial cellulosic ethanol plant in the United States opened in 1910 and failed after WWI.[3] In World War II, Germany synthesized diesel fuel from coal and the Japanese distilled turpentine from tree roots for airplane fuel. They both did this, not for any economic or performance advantage, but in desperation because Allied bombing and tanker sinkings had deprived them of petroleum. The US government spent $87 million between 1944 and 1953 on synthetic liquid fuel research involving military testing before dropping the program due to uncompetitive economics.[4] The Department of Energy (DoE) in 1977 focused research intently on ethanol as vehicle fuel. In 1980, in spite of record high oil prices, DoE formally abandoned the "Gasohol" program after acknowledging that physical limits of poor energy balance and extreme land use requirements made it impractical.[5] DoE also spent $25 million investigating microalgae under the "Aquatic Species Program" between 1978 and 1996, and $458 million on its "Biofuels Program" during that same period before shutting them down without achieving any breakthroughs.[6] The billions being spent today on entrepreneurial start-ups by the US federal government and military acting as venture capitalists are largely covering the same ground with the same result. Even advanced technologies such as genetic engineering cannot produce life forms that violate basic laws of physics and biology which will be discussed below.

Since 2008, a new generation of rigorous studies across the full spectrum of biofuels has been published that consider the full fuel production and consumption lifecycles at commercial scale, as well as the impacts of converting land to biofuel crop production. These studies have dramatically undermined the naïve assumption that biofuels are inherently clean and green, carbon-neutral, and America's ticket to energy self-sufficiency. But these watershed scientific documents have so far had little impact on US government or military energy policy. The US Navy directly rejected a RAND National Defense Research Institute study conducted at the direction of Congress and delivered to the Secretary of Defense in January of 2011 that unambiguously found biofuels of "no benefit to the military."[7] A second RAND study and a report by the US National Academy of Sciences that both severely questioned the wisdom and efficacy of current US biofuels policies also resulted in no adjustments to Environmental Protection Agency (EPA) or Department of Defense (DoD) biofuels programs.[8] In August 2012, the German National Academy of Sciences, of a country very aggressive in its pursuit of alternative energy, released the report of a 3-year study that concluded biofuels offer little or no benefit in reducing GHG emissions, and that "the larger scale use of biomass as energy source is not a real option for countries like Germany." The German scientists even went so far as to flatly recommend that all of Europe abandon their biofuel production mandates.[9] In October 2012, the National Research Council released a report which severely questioned the feasibility of algae-based biofuels and highlighted five areas of major concern that parallel and support arguments made in this paper against all cultivated biofuels.[10] These are but a few of the studies that point out critical and fatal flaws in pursuing biofuels as a substitute for petroleum, and this paper draws from scores more. Only if policy-makers are willing to roll up their intellectual sleeves and examine the tedious details do they have a chance to craft strategies grounded in realistic probabilities rather than baseless hopes. An effective energy strategy for the United States must be informed by history and exploit rather than defy the laws of nature in order to increase global stability and US security. It is important for all to approach this topic with a shared understanding of the relevant science, technology, and terminology.

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Section 3: The Science of Energy

3.1. Some Terms of Reference

Energy is a quantity of heat or work and can be measured in *joules*. A *primary energy source* is something obtainable from the environment that can be used directly for heat or work, or be made into a *fuel*. Candidates include crude oil, natural gas, coal, geothermal steam, uranium, wind, solar radiation, waves and tidal currents, food crops such as corn and sugarcane, cellulosic crops such as wood and switchgrass, and oil-yielding organisms such as soy and microalgae. An *energy carrier* is something that stores and transports energy for release under controlled circumstances. Examples include flywheels, electrical storage batteries, compressed gas, water collected behind a dam, and especially the chemical bonds of specific atoms such as hydrogen and carbon. Chemical energy carriers are generally packaged together with other non-energy carrier substances that make them easier to store and handle and consume. The resulting tailored combination forms a *fuel* that may be suitable for use within a given living or inorganic system, such as glucose for a plant or animal, or gasoline for an internal-combustion engine. *Combustion* is the chemical reaction of burning a fuel with oxygen (usually from ambient air) to release energy. *Power* is the rate at which energy is produced or consumed and can be measured in *joules per second*, otherwise known as *watts*.

The US Congress has authoritatively defined *energy security* in Title 10 of US Code as "having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet mission essential requirements."[11] In 2011, the United States imported 45% of its petroleum, and this fraction generates concern because of dependence upon other nations for supply and unpredictable global market price volatility.[12] If there exists a way to reliably supply US transportation energy exclusively from domestic sources with reasonable and stable prices, it would clearly enhance energy security. Advocates argue that every gallon of domestic biofuel is one less gallon of dependence upon foreign oil, and that producing enough biofuel will achieve oil independence and allow the United States to pull back its military forces from protecting the Persian Gulf. While it is a dubious proposition that current geopolitics and globalized energy markets and US relationships with international partners would allow for military disengagement from the Middle East, this paper does not challenge the argument on those grounds. Rather it is the first assumption that biofuels can substitute for and displace petroleum fuels that is the core issue addressed.

3.2. Basic Thermodynamics

An energy strategist must understand two unbreakable laws of the universe. The first law of thermodynamics (*conservation of energy*) essentially states that energy obeys the rules of checkbook math. The energy balance of a system, like the balance of a checkbook, is the sum of all deposits and withdrawals, and the withdrawals cannot exceed the deposits. Energy is not magically created from nothing nor does it disappear; it only moves between things or changes form. The second law of thermodynamics (*entropy*) distinguishes between two kinds of energy: useful energy that can perform work and useless energy that cannot. It holds that some fraction of useful energy irreversibly becomes useless energy every time energy is converted from one form to another. In other words, entropy is like an ATM fee that must be paid on all transactions. The bank of the universe deducts some percentage of every energy deposit, withdrawal, or conversion into its own account, leaving less as the customer's spendable balance. Together, these two laws declare that the amount of useful energy that can be recovered from a system is always less than the energy that was input into the system. This is why it is impossible to construct a perpetual motion machine. The more complex a process is in the number of steps and transformations required, the more usable energy will be lost along the way.

3.3. The Chemistry of Hydrogen, Carbon, and Nitrogen

The hydrogen atom is a principal energy carrier in many chemical fuels because it is abundant, is very reactive in accepting and releasing energy in its chemical bonds with other atoms, and is the lightest element, giving it a very high *gravimetric energy density* (joules per kilogram). Hydrogen gas (H_2) is a fuel of pure energy-carriers that can power everything from micro-organisms to turbine engines.

Carbon is another lightweight element with very high combustion energy that is an excellent energy carrier and fuel component. Carbon also has another highly desirable quality in that it readily forms long molecular chains and can serve as a backbone to organize many other atoms into dense and neatly organized packages–not unlike the plastic rings that hold six-packs of soda cans together. When it comes to hydrogen, carbon is a chemical miracle worker. Combined with hydrogen in equal parts it forms highly versatile and energetic liquid fuels. Higher carbon ratios yield solids and lower ratios yield gases. Carbon also performs the trick of packing hydrogen atoms together much more closely than they will tolerate on their own. This is why gasoline actually contains 63% more hydrogen atoms per gallon than pure liquid hydrogen does.[13] Because carbon also adds its own significant energy to the mix, gasoline has 3.5 times the *volumetric energy density* (joules per gallon) of liquid hydrogen. The addition of carbon transforms hydrogen from a diffuse and explosive gas that will only become liquid at -423°F, into an easily-handled room temperature liquid with more than triple the energy density and ideal volatility characteristics for a combustion fuel. If we didn't have carbon, we would have to invent it as the ideal tool for handling hydrogen.

Nitrogen, like carbon, also tightly packages hydrogen energy carrier atoms together to make an efficient fuel. One nitrogen atom bonds with three hydrogen atoms to form ammonia (NH_3). This combination of nitrogen and hydrogen is a potent organic fuel for most bacteria and plants, which have the ability to metabolize it directly or with each other's symbiotic help.[14] This fact is vitally important to properly understanding the role of ammonia-based fertilizers.

3.4. The Chemistry of Agriculture

A typical green plant contains more hydrogen than any other element—46 of 100 atoms are hydrogen, 32 are carbon, 21 are oxygen, and less than 1 in 100 is nitrogen.[15] Carbon and hydrogen store energy in plants in the form of various sugars and sugar polymers generically referred to as carbohydrates, and as lipids (fatty oils). Hydrogen ions and their liberated electrons are the fundamental energy currency of plant and animal metabolism.[16] One quarter of the combustion energy of typical plant biomass is in the hydrogen fraction, even though it constitutes only 6% of the dry weight. The remaining 75% of the energy is in the 50% carbon mass fraction. The nitrogen and oxygen fractions actually reduce the combustion energy density of the biomass.[17]

Carbon dioxide (CO_2) and water (H_2O) are the raw materials of photosynthesis, and they supply the carbon and hydrogen atoms, but they supply no energy. These compounds are the end-products of combustion, and their carbon and hydrogen are already depleted of all the free energy they carried. Plants, algae, or microbes must perform the chemical magic of "un-burning" CO_2 and H_2O and reforming their hydrogen and carbon back into carbohydrates and lipids that can once again power organic metabolism and support combustion. This requires the input of huge amounts of energy.[18] The attractive theory of biofuels is that all this energy can come for free as photons from the sun. However, the devastating limiting-factor for all biofuels is that photosynthesis captures solar energy with surprisingly poor speed and efficiency—only about 0.1% of sunlight is translated into biomass by the typical terrestrial plant,[19] and this translates into an anemic power density of only 0.3 watts per square meter (W/m^2) in the optimal conditions of the cloudless US southwest.[20] This is 20 times worse than the 6.0 W/m^2 that current solar panels arrayed in large farms can collect from the same sunlight and acreage.[21] Power density will be discussed in detail in its own section below, but the key point here is that the limiting factor for biomass growth is not just the availability of CO_2 and water, but the availability of input energy. Fortunately, plants have another avenue besides the sun to collect energy—the soil.

Carbon dioxide and water are the raw materials of photosynthesis, but they supply no energy.

Placing ammonia in the soil to fuel plant growth is known as "nitrogen-fixing."[22] This is done naturally through animal urine and manure, by the decay of protein matter from once-living things, by lightning, and through the action of symbiotic soil and root bacteria using photosynthesis energy borrowed from their host plant.[23] An historical look at crop records reveals that US corn farmers reached the limits of photosynthesis and natural nitrogen-fixing by the turn of the 20th century, and yields plateaued at 30 bushels per acre for a generation until another way to pump energy into plants was adopted.[24]

3.5. Giving Nature a Helping Hand

In 1909, Fritz Haber discovered the chemistry of converting natural gas into ammonia—i.e., converting fossil fuel into plant fuel. This allowed the creation and mass-production of modern ammonia-based artificial fertilizers with many times the potency of mineral salt and bio-waste fertilizers. His discovery so revolutionized agriculture that he won the 1918 Nobel Prize. The United States began to widely adopt ammonia-based fertilizers in the 1940s. Today's ultrahigh-yield crops have been bred and genetically engineered to pull much of their energy from artificially boosted soil ammonia rather than depending exclusively upon the sun and natural nitrogen-fixing. To provide this artificial plant fuel, the world converts massive amounts of natural gas into ammonia each year. The manufacture of ammonia is second only to plastics in consumption of US industrial energy,[25] and 86% of that ammonia goes into fertilizer.[26] Wherever "nitrogen" is used in the context of fertilizer today in the United States, it is almost certainly referring to ammonia. Virtually 100% of the 28 million metric tons of "nitrogen" fertilizer used each year are ammonia formulations.[27] An institutional pre-occupation with nitrogen and a lack of appreciation for ammoniacal hydrogen in evaluating the energy balance of plants and fertilizers is likely one of the principal reasons why the deficiencies of biofuels are not readily recognized by many agricultural professionals. It is largely because of this conversion of fossil fuel energy into food that humanity has avoided Robert Malthus' 1798 prophecy of global famine from population growth overtaking food production.

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Without artificial fertilizer, crops grow much more slowly and yield far less per acre than we have become accustomed to in the modern world. The largest yield of corn in the United States prior to ammonia fertilization was 31.7 bushels per acre in 1906.[28] Today, Iowa farmers pump pure liquid ammonia into the soil at the rate of 150-200 lb/acre to harvest consecutive annual crops of 160-180 bushels per acre of corn—a six-fold increase.[29] The amount of sunshine flooding an acre of Iowa cropland has not changed since 1906. Rather, five-sixths of the increase in the modern corn harvest is attributable to altered genetics and improved intensive farming efficiencies that take advantage of hydrogen and nitrogen energy artificially placed in the ground in massive quantities by humans. US Department of Agriculture historical data show that corn yields were flat through two generations of hybridization and farming innovation and mineral nitrogen fertilization following the civil war, but exploded beginning in the early 1940s when ammonia plants built to make explosives for the war effort began also to supply ammonium nitrate fertilizer for agriculture (Figure 1).[30] Choosing not to artificially fertilize with ammonia would send corn yields plummeting back toward their natural 1906 value and greatly increase the needed land acreage for the same harvest.[31]

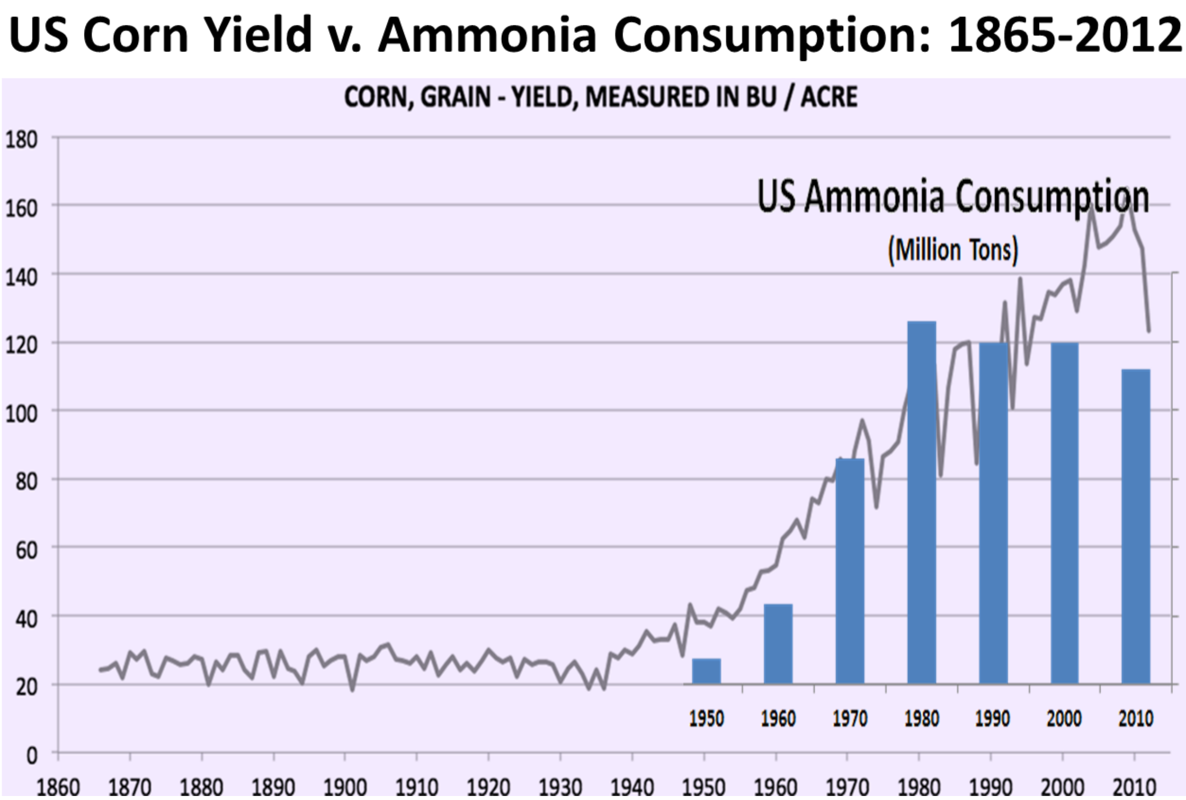

Figure 1. US Corn Yields and Ammonia Consumption

Despite emphatic claims from snake oil salesmen who use terms like "drought-loving" when they mean "drought-tolerant," all crops must obey the laws of thermodynamics and can only yield energy output in biofuel significantly less than the energy input to grow them. Switchgrass, jatropha, miscanthus, and other species that are often claimed to thrive in marginal circumstance, only produce the high yields promised in the investment brochures when benefiting from liberal application of water and fertilizers and herbicides and pesticides as is duly noted in published research. For example, switchgrass takes as long as 30 years to fully develop on unmanaged land as part of a natural prairie biome, and 3 years to produce a full yield even as a cultivated monoculture—and it depletes soil nutrients like any other vigorous crop.[32] Without boosting from artificial fertilizers, meaningful annual yields of biofuel crops are not sustainable. There is no free lunch. India is one of many countries where farmers have recently been victimized by promises of miracle crops only to be ruined by results that were an order of magnitude lower.[33]

3.6. Summary of the Science

Whether discussing fossil fuels or biofuels, the combustion energy is in the hydrogen and carbon. Those who advocate a transition to a "hydrogen economy" fail to appreciate that our world (organic and industrial) already runs on a hydrogen economy–one enabled by carbon and nitrogen. Thermodynamics and chemistry teach us that we reduce the usable energy content of a primary energy source with every step of converting it to a fuel. Biology and physics show that photosynthesis places a cap on the natural power density of biofuels that limits them to yields which are far below other alternatives (and which will be shown to be far below the minimum that modern civilization requires). To overcome the solar-limit on biomass production for food crops, humans have figured out how to input fossil fuel energy in the form of ammonia fertilizers. While this is a justifiable option to increase food production, it makes no sense to add energy to something that is supposed to be an energy source such as biofuel crops. It is also nonsensical to add fossil fuel energy when the objective is to reduce the use of fossil fuels. It is even worse to do this knowing that the process of converting fossil fuel energy into biomass is hugely wasteful of energy. Before proclaiming which energy sources will supply America's future needs, energy strategists must understand the demand side of the equation in terms of both quantity and quality.

Section 4: The Fuel Needs of Modern Civilization

4.1. The Petroleum Standard

The US population and economy consume more than 102 exajoules of energy a year (exa = quintillion). More than 1/4 of this energy—28 exajoules—is consumed as liquid combustion fuels used for transportation (i.e., gasoline, diesel, avgas and jet fuel). A perfect combustion fuel possesses the desirable characteristics of easy storage and transport, relative inertness and low toxicity for safe handling, measured and adjustable volatility for ready mixing with air, stability in its characteristics across a broad range of environmental temperatures and pressures, and—of critical importance—high energy density. Because of sweeping advantages across all these parameters, liquid hydrocarbon fuels refined from petroleum have risen to dominate the global transportation economy and ushered in a jet age and space age that would not exist without them. Conventional diesel, jet fuel, and gasoline are the gold standards for transportation fuels.

Liquid hydrocarbons are the gold standard for transportation fuel and have singularly enabled the jet age and space age.

Any candidate to replace refined petroleum has quite a high bar to vault in terms of physical performance. The list of candidates with superior volumetric energy density is short and comprises only solids.[34] Fuels derived from biomass are markedly inferior in performance. Biodiesel is not a hydrocarbon but a cocktail of fats cut with alcohol that tends to solidify in cold temperatures. Ethanol is even further from a hydrocarbon and is corrosive to pipelines and vehicle fuel systems. Pyrolysis bio-oil is a highly acidic and chemically unstable brew of over 300 different organic compounds. All three biofuels contain oxygen, are more soluble in water, and are more conductive of electricity than hydrocarbons, all of which promote the contamination and corrosion of fuel systems. The physical characteristics of all three make them incompatible with the world's huge capital investment in petroleum storage and pipeline infrastructure, greatly restricting their availability and utility.[35] They all have lower energy density than their hydrocarbon counterparts. Moving a given quantity of energy around a battlefield as biodiesel instead of petroleum diesel would require 8% more tanker trucks, ethanol or bio-oil 65% more, liquid hydrogen 280% more. Substituting biobutanol, biogas, ammonia, fuel cells, capacitors, or batteries in place of hydrocarbons on the battlefield would require even longer convoys that expose more Soldiers and Marines to enemy attack, not fewer.[36] Increasing fuel efficiency of military equipment or buying fuel locally are the only ways to reduce convoys.

4.2. Hydrotreated Biofuels

To overcome all the above limitations and make biofuels into the "drop-in" replacement fuels that are fully compatible with existing fuel infrastructure and military and civilian engines, their alcohols and lipids and mystery molecules must be transformed into true hydrocarbons by a complex series of processes collectively known as *hydrotreatment*. These chemical manipulations increase the ratio of hydrogen to carbon, remove all oxygen, and change the structure and blend of the constituent molecules to give the fuel its necessary characteristics.[37] Hydrotreatment greatly increases the cost, reduces the energy benefit, and undermines claims of renewability for the resulting fuels because it requires the addition of fossil fuel hydrogen derived from natural gas and releases 11 tons of CO_2 for every ton of hydrogen added. A national security energy strategist must understand these technical but vital details and also be aware that *all military aircraft and combat vehicles and civilian airline fleets can only use hydrotreated biofuel* even as additives and blends of conventional fuels. Besides all the inherent performance advantages of hydrocarbon fuels, there is an even more fundamental reason why refined petroleum fuels dominate.

Section 5: Energy Return on Investment

For energy strategists to get the right answers, they must first ask the right questions. When choosing a primary energy source and a fuel to derive from it, it is essential to be sure the fuel will meet the demands of the civilization that will consume it. Raw primary energy sources require some energy to be consumed to process them into finished fuels. One key measure of a fuel's usefulness to civilization is how much useful energy it yields as fuel divided by how much energy was required to extract the primary energy source from the environment and convert it into that fuel. This metric is known as *energy return on investment* (EROI).[38]

$$\text{EROI} = \frac{\text{Energy usable in newly produced fuel}}{\text{Energy consumed in producing the new fuel}}$$

An EROI of 1:1 would mean that the useful energy in a newly produced quantity of fuel is exactly equal to the energy consumed to produce it. It might seem that any EROI greater than unity is of net benefit to civilization—but this is false. A modern civilization requires a much greater return on its investment than this because survival and standard of living depend upon the size of this margin. To help quantify what civilization requires of its energy sources, it is helpful to look at how the laws of physics apply to living organisms.

5.1. Civilization Is a Living Organism

Dynamic Energy Budget (DEB) theory is a sophisticated approach to looking at living things in terms of energy.[39] A thermodynamic analysis reveals that any organism can only afford to expend a small fraction of its current energy stores finding and processing new primary energy sources into fuel (*assimilation*) because there are many other essential energy-consuming (*dissipation*) tasks it must perform to survive; these include sustainment, repair, protection, maturing and increasing in complexity, and reproduction. Only if there is surplus energy after all of these demands are fully satisfied will the organism increase its mass (*growth*). To power all these activities, the organism needs food that is not just fractionally positive in net energy, but rather has an EROI many multiples greater than unity. A civilization is itself a high-order physical and biological organism that has tremendous overhead costs and can spare only a fraction of its energy to assimilate new energy. One researcher exploring the linkage between physics and economics has found an historical linear relationship between global civilization's accumulated physical mass (i.e., net value of accumulated capital) and its appetite for energy, with a value of 9.7 milliwatts per 1990 US dollar.[40] This same approach also revealed a similar linear relationship between civilization's wealth and the amount of CO_2 it exhales.[41]

Furthermore, this econo-physics research and the theory of biodynamics both support a concept in conventional economics called "Jevon's paradox," which holds that increasing energy efficiency *increases* energy demand. This counterintuitive outcome is due to the difference between living things and machines: a living organism that adapts to use its quota of food more efficiently will gain more body mass and thus increase its appetite for food. This behavior was first observed in patterns of steam engine improvements and coal use by William Stanley Jevons in 1865, and is an historically-validated truth that throws a huge wrench into policy-makers' efforts to control global warming GHG emissions by legislating efficiency improvements. Efficiency gains are observed to raise standard of living rather than reduce consumption. This is not to say efficiency is a bad thing–it also makes an organism more competitive in a resource-constrained environment. However, efficiency and conservation are two distinct phenomena. Conservation (i.e., reduced consumption) is a response to resource scarcity and higher prices. Civilization, like all living things, is stubbornly biased toward growth and never voluntarily leaves food on the plate. Understanding Jevon's paradox also allows one to detect that many of the predicted trajectories of atmospheric CO_2 are likely too low because they wrongly apply energy efficiency corrections. Energy strategists must realize that civilization is a living organism, not a machine, and apply the correct principles of biology and economics and physics to make accurate predictions and effective policies.

5.2. EROI of Ancient Civilization

EROI is a function of both the energy profit inherent in a primary energy source and the efficiency of prevailing technology in converting that energy profit into fuel and then into work output. An insightful historical analysis of the construction of the Roman Colosseum yields data from which one may calculate an EROI for the grain-based economy of first century Roman civilization.[42] At peak efficiency, humans and oxen fueled by organically cultivated wheat and alfalfa were capable of delivering a maximum EROI of 4.2:1 calculated as the ratio of their output physical work to the input of crop farming resources and labor necessary to feed them. In the course of the five-year construction of the Colosseum, the Romans actually achieved an EROI of approximately 1.8:1 due to various practical limitations including 145 no-work holidays a year.[43] Western civilization's EROI dropped during the Middle Ages as the Empire's enormous and efficient *latifundia* crop plantations disappeared.

Rome's peak was only surpassed 1,700 years later when steam engines were developed that could extract high EROI work from coal, ushering in dramatic increases in standards of living, and ultimately helping industrializing nations to move away from dependence upon draft animals and slaves. Later, petroleum's high EROI, higher energy density, and extreme versatility enabled the transportation revolution of aircraft and rockets. To appreciate the magnitude of this energy revolution, consider that three tablespoons of crude oil contain the equivalent of eight hours of human labor, and a car's tank of gasoline contains approximately two man-years of energy. An average American household benefits from the equivalent of hundreds of virtual servants in the form of the heat and electricity and transportation it enjoys courtesy of hydrocarbon fuels. It is clear that the energy-hungry cars, washing machines, air conditioners, and airplanes of modern civilization can only be sustained with higher EROI fuel than that available to Rome, but the question is, how much higher?

5.3. EROI of Modern Civilization

A study of historical US economic performance over the last century has found that recessions are linked to overall fuel EROI dipping below a critical threshold of 6:1.[44] This value represents the minimum energy quality civilization must have to sustain a modern, energy-intensive quality of life. Another macro-analysis found that an EROI of 3:1 is the bare minimum quality a raw energy feedstock must have to overcome all production costs and conversion losses and still deliver any positive net energy to modern civilization.[45] To put these values in biological terms, a modern post-industrial civilization is very energy-hungry, and if undernourished on a diet of fuels with lean EROIs below 6:1, becomes catabolic: eating into the fat of its savings and the muscle tissue of its infrastructure to replace the missing calories. As long as EROI remains below 6:1, industrial civilization is locked into a death spiral where an ever increasing fraction of its economic output (GDP) is spent on energy at the cost of an eroding standard of living.[46] In economic terms, this exactly describes what is commonly known as a recession, or, more accurately, a contraction. At EROIs below 3:1, the fuel is so poor that digesting it takes more energy than it returns, and full starvation sets in. The only way out of this hunger trap is either to find higher EROI energy, or to decay into a pre-industrial civilization with lower energy needs.

A modern economy slips into recession if net fuel EROI drops below 6:1, and starves if EROI drops below 3:1.

The bottom line is that the economy of a modern developed nation slips into recession if its net fuel EROI drops below 6:1, and starves if EROI drops below 3:1. The inevitable consequence if such low EROIs persist is industrial collapse and regression of civilization to agrarian-age economics (Figure 2). Purposely displacing high-EROI energy sources with anything that returns less than 6:1 is to foolishly and harmfully push economies toward recession and civilization toward regression. It will have the same effect as starving a human with a diet of hay. Plotting out primary energy source and fuel EROI estimates versus their current energy contribution to the US economy provides a useful perspective on their relative utility (Figure 3).[47]

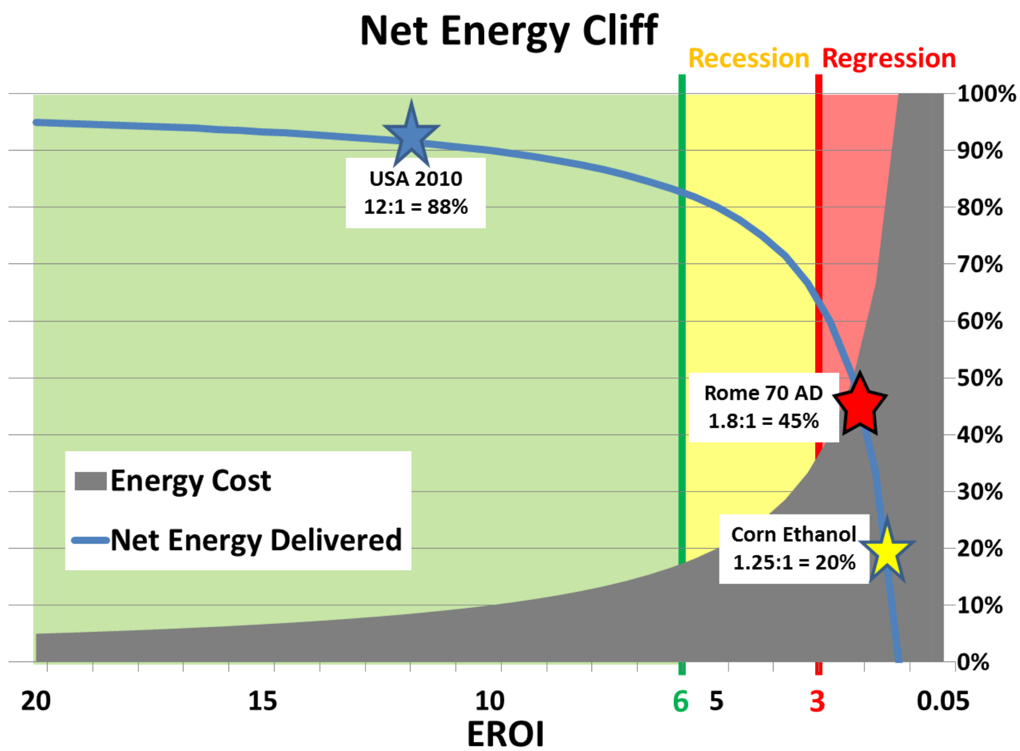

Figure 2. Net Energy Cliff

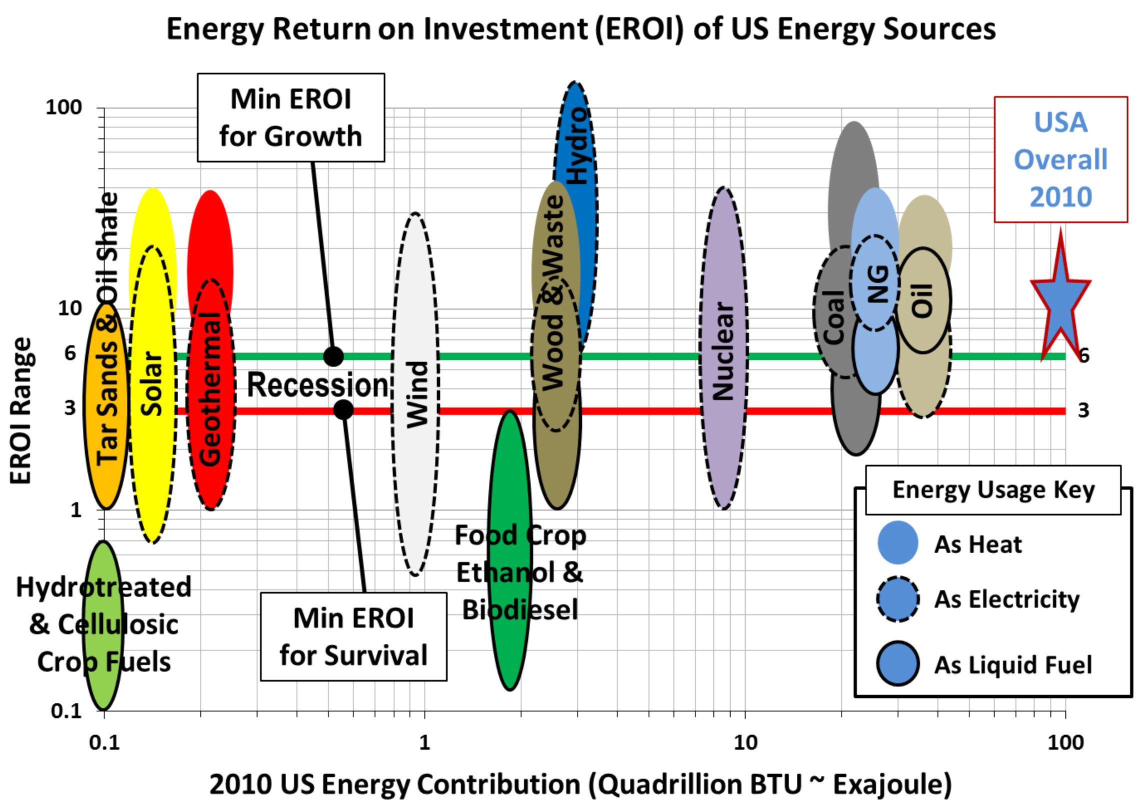

Figure 3. Energy Return on Investment (EROI) of US Energy Sources

Section 6: Evaluating Biofuels

6.1. Food Crop Ethanol

Over the past 70 years, the United States has nearly perfected corn as a high-yield food and industrial starch feedstock. The conversion of corn kernel starch to ethanol has been optimized, yielding nearly 500 gallons per acre per year. Unfortunately, corn's dependency upon fossil fuel and the thermodynamic penalties paid for even this relatively easy biofuel transformation is such that, after decades of study and experimentation and continuously refined commercial production, the scientific literature consensus for corn ethanol EROI is a lowly value of 1.25:1.[48] Even worse, there is no net gain in liquid fuel energy—the produced ethanol contains energy barely equal to the input fossil fuel energy. The small energy profit is contained in a high-protein byproduct of distillation called "distillers' dry grains and solubles" (DDGS) that can supplement animal feed. The stark reality is that more than $6 billion a year in annual direct federal assistance to corn growers and ethanol refiners since 2005 has served only to reduce a non-existent foreign dependence on animal feed.

Billions of dollars in corn ethanol subsidies have served only to reduce a non-existent foreign dependence on animal feed.

Sugar beet and sugarcane are more expensive feedstock for ethanol than corn in the United States and Europe, but a bit simpler to convert into ethanol.[49] A spectacular 8:1 EROI for Brazilian sugarcane is often cited, but examination of the calculations reveals that this is a different computation known as External Energy Ratio.[50] When the huge internal energy cost of burning cane straw (bagasse) for distillation heat energy is properly counted, the EROI corrects to less than 2:1 in line with US and European figures.[51] The cane is first burned in the field to remove leaves, trash, and rodents, and then the bagasse left after crushing out the sugar is burned for heat to distill the fermented ethanol. The entire process is hugely damaging to air quality, and bagasse-fired sugar and ethanol refineries smoke like 19th century steel mills.[52] The myth of Brazilian sugarcane ethanol is further deflated by recently declining crop yields due to unsustainable farming practices. Yields per hectare fell 18% in the 2011-2012 season due to depleted soil and pest damage, and the government was forced to respond by lowering the gasohol blending ratio last October from 25% to 20% and by *importing* 1.2 billion liters of ethanol.[53] New sugar-ethanol plant construction in Brazil peaked at 30 in 2008 and is now down to near zero. Ethanol use there appears to have plateaued, and though it is not yet well known, US ethanol production just peaked this year as well and is projected to fall in 2013.[54]

Corn and sugarcane, along with other cultivated food crops such as sugar beet and sweet sorghum, represent the most productive of biofuel feedstocks in terms of fuel yield per acre. Farmed seaweed (macro-algae) has the potential to join but not surpass this group with further technology development. The relatively high fraction of easily processed sugars and starches in these crops is precisely why they are cultivated for food—and fuel. Nevertheless, their yields without cultivation are too low to serve as significant energy sources, and their EROIs as cultivated crops are nowhere near high enough to keep America's economy out of recession.

6.2. Cellulosic Ethanol

Cellulose and lignin are super-strong sugar polymers that form the bulk of green plant structure such as stalks, stems, trunks, blades, and branches. Cellulose forms the interlocking fibers that provide tensile strength, while lignin is the cell wall armor plating that provides rigidity and compression strength. These materials are much harder to digest into food or fuel than the easy starches and sugars of food crops. Evidence of the intrinsically poorer fuel feedstock quality of lignocellulose is apparent in biological metabolism. A human can live on a starchy corn kernel diet, but will starve eating corn stalks or cellulosic grass without the four-chambered stomach of a cow and the devotion of all waking hours to grazing and chewing cud. Lignin is so chemically stubborn that the only practical way to retrieve chemical energy from it is to burn it as a solid directly for heat. Cellulose can be broken down into fermentable sugars, but must first be separated from the lignin. Paper manufacturers have been working this problem for centuries and have found no better alternative than a combination of concentrated acid and explosive steam treating known as the "Kraft process." However this one step alone consumes as much energy as exists in the final ethanol. Those who want to make a liquid fuel out of lignocellulose must use much slower and more expensive enzyme or microbe-assisted processes to have any hope of preserving some net energy. After separation, pure cellulose (same solid material as cotton fiber and cellophane) must be further broken down into component sugars by tons of water and truckloads of yeast and designer enzymes (most likely synthesized from petroleum feedstock). Then there still remains the very energy- and water-intensive separation, distillation and dehydration steps to reduce the 4% alcohol "beer" solution to 99.5% pure anhydrous alcohol that can be added in small quantities to gasoline without voiding manufacturer warranties. To make a fully substitutable motor or jet fuel, alcohols can also be hydrotreated, but at even more energy loss and expense than biodiesel.

A rigorous thermodynamic analysis has predicted cellulosic ethanol to be three or more times more difficult to produce than food crop ethanol, with lower yields and with an EROI far below 1:1.[55] However, a much-touted USDA study that assumed away many of the known difficulties and costs to predict a fancifully EROI for switchgrass of 5.4:1 (four times better than corn ethanol) is the more often-cited paper, and has been used to justify spending billions of dollars in federal and private funds on some high-profile entrepreneurial misadventures.[56] However, the proof is in the performance. Despite all the subsidies and tax breaks and fuel mixing mandates emplaced and accelerated since 2005, the National Academy of Sciences recently acknowledged that there is not a single commercially viable cellulosic ethanol facility in the United States today.[57] Rather, the landscape has been rocked by high-profile collapses such as the demise of Range Fuels, signature creation of vocal biofuels proponent Vinod Khosla and recipient of the first USDA biofuels loan guarantee of $64 million in 2010.[58] This failure eclipsed the 2009 fraud scandal and implosion of Cello, which was the Solyndra of cellulosic ethanol. As of the writing of this paper, ZeaChem Inc., founded in 2002 and recipient of $297.5 million in grants and loan guarantees from the DoE and USDA, is operating its 250,000 gallon per year biorefinery in Oregon as a demonstration facility, which means the product is not commercially competitive.[59] Shell has spent almost $400 million on cellulosic ethanol at Codexis with no commercial progress to show for it.[60] BP and KiOR and others have recently cancelled or suspended or delayed construction of huge cellulosic bio-refineries in the United States.[61] Instead of the 500 million gallons of cellulosic ethanol that huge cumulative subsidies and guaranteed markets were promised to deliver by 2012,[62] the EPA officially counts only one commercial transaction to date—a 20,069-gallon sale of Brazilian sugarcane bagasse ethanol from Blue Sugars Corporation's demonstration facility to an undisclosed buyer last April.[63] Some of the companies who've been working on cellulosic ethanol the longest such as Gevo, Amyris, and Cellana, have shifted to corn ethanol, industrial chemicals, and fish food.[64] Around the world, cultivated food crops (corn, sugarcane, soy, palm, and various oilseeds) account for all statistically significant liquid biofuel production.[65] Nevertheless, the EPA continues to fine US oil refineries for not mixing non-existent cellulosic ethanol into their gasoline.[66]

Instead of the 500 million gallons a year promised, total commercial cellulosic ethanol production to date is 20,069 gallons.

Two new cellulosic ethanol biorefineries have recently started operations and their performance in the coming months should be revealing. In the fall of 2012, KiOR opened a 10 million gallon-per-year biorefinery in Mississippi that investors and the EPA have been promised will deliver commercial sales and profits from competitively-priced gasoline and diesel made from trees. INEOS Bio likewise commissioned an 8 million gallon-per-year commercial cellulosic ethanol plant in Florida. However, expectations for these massive capital investments are already being deflated by relabeling "commercial" to "commercial demonstration" or "second generation demonstration," and shifting profitability target dates to future years. Even if these plants somehow achieve marginal profitability with a stacked deck of biofuel subsidies and blending mandates and carbon taxes, they will still face an insurmountable capacity challenge because of abysmal power density, as will be discussed shortly. Meanwhile, some of the companies who've been working on cellulosic ethanol the longest such as Coskata and Primus Green Energy are quietly leading a mass migration away from any pretense of renewable fuels, to instead boldly embrace synthetic liquid fuels made from cheap natural gas.[67] In the end, even the enzymatic and microbial processes entail large net energy losses with an EROI far below 1:1 for cultivated biomass. To find out exactly how bad the numbers are, one would have to ask people like the former CEO of Codexis, who has publically confessed that making hydrocarbons from carbohydrates is a dead end, and who is now at Calysta working on natural gas-to-liquid fuel.[68]

6.3. Biodiesel

A third option, besides growing a plant for its starches or cellulose, is to grow it directly for oil. Species which yield some biomass as lipids include soy, camelina, rapeseed, oil palm, jatropha, peanut, sunflower, cottonseed, safflower, and microalgae. All of these crops, including a non-poisonous Mexican variant of jatropha, have provided human and animal food over the centuries. The natural lipids in these plants can be broken down by adding methanol (made from natural gas) to convert them into a soup of fatty-acid methyl esters (FAME)–commonly known as "biodiesel." Lipid fractions of plants are generally small compared to starch fractions, and that is why soy biodiesel yields per acre are much smaller than corn ethanol yields (70 gal/acre v. 500 gal/acre) and consume so much more water per liter of fuel, as will be discussed later.[69] Soy Biodiesel EROI calculated from rigorous, full commercial-scale lifecycle studies is slightly better than corn ethanol at 1.9:1, but still nowhere close the 6:1 threshold for minimal utility.[70] The well-known oil fraction limitation of terrestrial plants is why there has been 80 years of research on fast-growing, higher lipid fraction micro-algae as a way to get a high-yield biodiesel crop.[71]

Algae is the only biodiesel crop with high enough potential yields to replace US petroleum without consuming all US territory as cropland, so it is worth a detailed look. All plants, including algae, stubbornly want to produce carbohydrate structural biomass instead of lipids because that is how they grow and reproduce. Lipids are an intermediate synthesis product that are only accumulated in larger amounts when the plant is starved of some essential nutrient such as nitrogen or silicon essential to complete biosynthesis of new structural biomass. Lipid yield in g/m^2 of pond or bioreactor surface area is a function of the number of algae cells and their individual lipid fractions. Absolute yield is limited because one can either starve the algae to produce more oil or feed them to foster reproduction, but not both—another *catch-22*.[72] In addition, lipid fraction controls buoyancy for algae. It cannot be increased beyond the point where the algae float to the surface, crowd out the sunlight, dry out, and die. These are physical and biological limits known from previous research under the Aquatic Species Program. It is not possible to change basic physical laws such as Archimedes' principle of buoyancy with even the most sophisticated genetic engineering.

Additionally, attempts to move algae from the lab bench to commercialization continue to be crushed by poor EROI. A literature survey of reported algae EROIs performed by the National Research Council found values from 0.13:1 to 7:1, but in the higher cases, energy credits from co-products dwarfed the energy delivered as biodiesel—biodiesel was really the co-product and solid biomass the product.[73] If there is any benefit and profit to be made from algae, it appears to be more in producing soylent green than in producing green fuel. A critical look at the more optimistic studies that predict the higher EROIs reveals that they depend upon a host of unrealistic assumptions—massive supplies of free water and nutrients, a free pass on enormous environmental impact, and market economics that miraculously transform the huge burden of enormous accumulations of soggy byproduct biomass that has per-ton value less than the cost of transportation into a cash commodity crop. Proponents often claim that algae need only sunlight and CO_2 to grow. However, to make the high yields promised, fertilizer energy is typically supplied in the nitrogen, carbon, and hydrogen molecules of a solid form of ammonia called urea.[74] Solazyme Inc., the US Navy's choice for algae biofuel and recipient of a $21 million DoE biorefinery grant,[75] actually grows their product in dark bioreactors, feeding it carbon and hydrogen energy in the form of sugar. This makes them unique in producing a biofuel 100% dependent upon a food crop and getting 0% of its energy from the sun via direct photosynthesis—a worst case scenario.[76]

The most realistic, full-scale, full commercial lifecycle studies find a break-even 1:1 EROI if the algae biomass is simply sun-dried and shoveled directly into a furnace for heat.[77] Any attempt to convert to liquid fuel results in a large negative energy balance. Hydrotreating further destroys EROI, as can be seen in prices paid by the US Navy for algae biofuels below. The simple but decisive math is that, even at commercial scale, with generous assumptions about cellular reproduction rate and lipid fraction and oil extraction, and ignoring the costs of facilities and water, Argonne National Laboratory calculated that it takes 12 times as much total energy and 2.6 times as much fossil fuel energy to put a gallon of non-hydrotreated biodiesel in a gas station pump instead of a gallon of petroleum diesel.[78]

6.4. Fast Pyrolysis Bio-Oil

One byproduct of the Kraft process discussed above that paper companies use to separate cellulose from wood is "tall oil" or "pine oil." An alternative *fast pyrolysis* process uses heat, catalysts and in some cases solvents to maximize the production of "bio-oil" from wood feedstock instead of the separation of cellulose. Fast pyrolysis is able to convert up to 70% of the feedstock wood into bio-oil. However, the product oil is far inferior in its engine compatibility to even ethanol without extensive reprocessing and hydrotreatment. Raw bio-oil has about the same energy per gallon as ethanol, but each gallon is 50% heavier.[79] Its formula is highly variable depending upon the specific process temperatures, pressures, catalysts, solvents, and filtration, as well as what plant species is the feedstock of the moment. Bio-oil has been tested to contain over 300 different compounds in varying proportions including acids and metals. It has a high ash content, high moisture content, high oxygen content, low volatility, low overall quality, and a typical pH of 2.0-3.0, which is so acidic that special stainless steel is needed for processing.[80] It also has a very limited shelf life in that it rapidly polymerizes into a viscous semi-solid. Processes are still being developed to filter out the ash and metals and to stabilize shelf life, but all the steps required to transform bio-oil into a reasonable petroleum substitute promise a very poor EROI.

As with algae, economic viability depends upon being able to monetize leftovers and byproducts into lucrative commodities, and being given an environmental pass—in this case on unprecedented massive commercialization of forest land. Fast pyrolysis typically produces large volumes of organic-laced wastewater that must be treated, and the major co-product is "bio-char," which is a term of art for charcoal powder. Bio-char is touted as a soil "conditioner" and carbon sequestering mechanism, but its benefits are completely overshadowed by the soil acidification and N_2O GHG emissions of nitrification if any ammonia fertilizer is used for the feedstock crop.[81] Bio-char also presents considerable handling challenges as it is a flammable powder that is explosive and toxic when airborne. EROI is poor because much of the original feedstock combustion energy is lost in the pyrolysis process and more is carried away in the unused bio-char at the rate of 30 million joules per kg.[82] Synthetic gas is also a co-product, but is generally fully consumed onsite to augment the bio-char, natural gas, or other sources of heat used to drive the pyrolysis process.

Economic viability of algae biodiesel and pyrolysis bio-oil depends upon being able to monetize byproducts into lucrative commodities.

If fast pyrolysis magically converted 100% of tree energy into liquid fuel energy with zero thermodynamic losses, the power density of the process, without boosting with fossil fuel fertilizers, would be limited to the photosynthesis limit previously discussed of 0.3 W/m2. Under these ideal conditions, satisfying the nation's transportation fuel needs of 28 exajoules per year would require harvesting the annual growth of 731 million acres of trees, which happens to be about the exact total of forest in all 50 states.[83] If all 800 species of trees in all 750 million acres of biodiverse US forest habitat were replaced with fast-growing monocultures of pulpwood that mature in 25 years, the United States would have to fell 30 million acres of trees a year for pyrolysis transportation fuel. When adjusted for actual yields and EROI of a realistic fast-pyrolysis process at scale, the required acreage goes up by many multiples. Numbers like these are why many environmental organizations including a nine-nation European consortium have begun to come out strongly against biofuels.[84]

Section 7: Fuel Lifecycles and Opportunity Cost

Direct comparison of competing alternatives is a sound evaluation technique and introduces the important economic concept of *opportunity cost*. Not only should new fuels have an EROI greater than 6:1 as a threshold criteria, they should also have a competitive EROI equal to or greater than available alternative fuels suitable to the same purpose. If they have a lower EROI, and their use is compelled, their production will parasite energy from higher EROI fuels and their use will be an energy sink to the economic sector they serve.[85]

7.1. Fossil Fuel versus Corn Ethanol

Current petroleum diesel and gasoline production EROIs are variously estimated between 10:1 and 20:1.[86] Taking a conservative approach least favorable to petroleum, this paper will postulate an 8:1 EROI for purposes of comparative analysis, which represents the lowest ebb of crude oil calculated since 1920.[87] An 8:1 EROI means that 1 barrel of liquid petroleum fuel energy input[88] can support the exploration, drilling, extraction and refining of enough crude oil to make 8 new barrels of liquid petroleum fuel energy—which happens to come with a bonus of 1 barrel of chemical feedstock for plastics, lubricants, organic compounds, industrial chemicals, and asphalt (See Figure 4).[89] The much lower 1.25:1 EROI of corn ethanol means that, to produce the same net gain of 8 barrels of energy requires *not 1, but 32 barrels* of input energy. And for ethanol, the output energy profit is delivered not as liquid fuel, but as 5.5 tons of animal feed co-product. The 52 barrels of lower energy-density, lower compatibility, and more corrosive ethanol produced as the primary product contain just enough energy to make up for the 32 barrel-equivalents of fossil fuel energy used to make them, and deliver no net energy gain. The dramatic difference between this picture and what one finds in biofuels advocacy propaganda is fourfold. Firstly, this view portrays the whole fuel creation and consumption lifecycle instead of just a misleading combustion-only comparison of a barrel of oil versus a barrel of ethanol. Secondly, it holds energy output as the constant between the two cases, because civilization demands energy, not barrels or bushels. Thirdly, it balances mass and energy inputs and outputs as is required by the laws of thermodynamics. Fourthly, it demonstrates the essential economic concept of *opportunity cost*—in this case how a given amount of invested energy can deliver wildly different outputs of usable fuel depending upon the path taken.

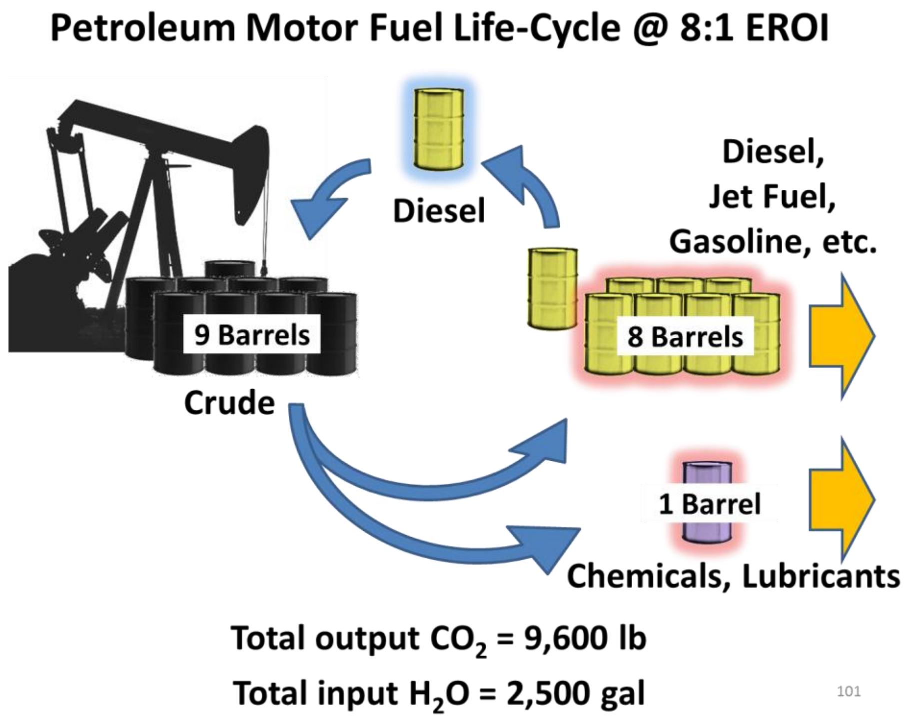

Figure 4. Petroleum Motor Fuel Lifecycle

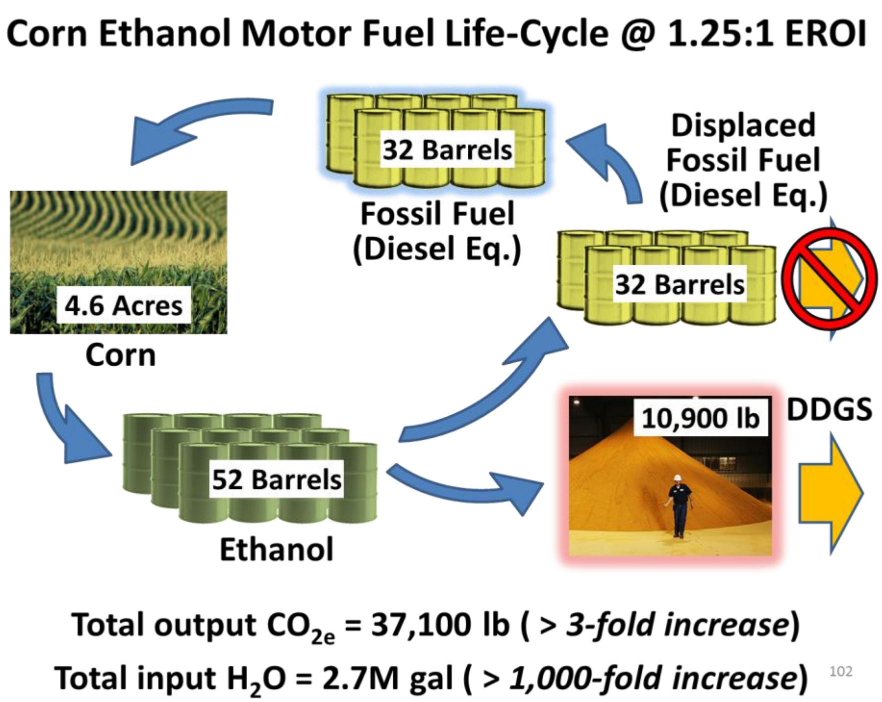

Figure 5. Corn Ethanol Motor Fuel Lifecycle

To summarize the corn ethanol fuel lifecycle depicted in Figure 5, it is the transformation of 4.7 tons (180 gigajoules) of high-quality fossil fuel and 11,000 tons of fresh water into 7.2 tons of lower-quality ethanol fuel-additive (180 gigajoules) and 18.5 tons of CO_{2e}, all for the net energy output of 5.5 tons of animal feed.[90] From the perspective of opportunity cost, one barrel of fossil fuel energy can either deliver 340 pounds of animal feed or 2,200 pounds of refined petroleum fuel (336 gallons, 1 metric ton), and the latter with lower lifecycle GHG emissions and much lower water use. Compared to the petroleum fuel lifecycle (Figure 4), the corn ethanol fuel lifecycle (Figure 5) consumes 3.5 times more fossil fuel, more than triples GHG emissions, increases water use by three orders of magnitude, adds environmental costs from agriculture while still suffering those associated with fossil fuels, and competes with food cultivation for the necessary land acreage and other agricultural production capital and resources. If high-protein animal feed supplement is the object, the much more efficient and economical path generally chosen by US farmers in the absence of ethanol subsidies is growing soy, which fixes its own nitrogen and has 49% protein content vice 27% for DDGS.[91]

The investment of one barrel of fossil fuel energy can either deliver 340 pounds of animal feed or 1 metric ton of refined petroleum fuel.

7.2. Parasitic Dependence and Hybrid EROI

This comparative EROI methodology can be applied to other biofuels as well. It shows that lower EROI fuels (e.g., corn ethanol) drag down the overall average and multiply rather than reduce the consumption of higher EROI fuels (e.g., refined petroleum). Civilization's demand for energy is the constant that must be met. Lower EROI fuels, by definition, require a higher investment of energy upfront to deliver the same energy output as higher EROI fuels. Biofuels can only truly substitute for fossil fuel fuels when the EROIs of both converge, and this cannot happen if the former is an energy parasite of the latter. Biofuels in the United States are not displacing fossil fuels, they are accelerating their use. The only way to displace imported petroleum, and thereby improve national security, is to domestically produce fuels with higher EROI than refined petroleum. Any such fuel will be instantly adopted because the evidence of its higher EROI will be a lower price.[92]

It is also important to understand that the corn ethanol EROI discussed above and those published in the literature are not for a pure corn ethanol lifecycle, but for a hybrid lifecycle involving both fossil fuel and corn ethanol, where fossil fuel provides much of the input energy. A proper corn ethanol EROI would be calculated using corn ethanol and sunlight as the exclusive energy sources to make more corn ethanol. This author could find no example of corn ethanol (or any biofuel) being used as the exclusive energy source for making more of itself, and the reason is easy to deduce. Knowing the EROI contribution of the external fossil fuel inputs and the overall EROI of the hybrid process, it is possible to derive the internal EROI of processing corn into ethanol. Dividing the 1.25:1 hybrid EROI by the 8:1 fossil fuel EROI yields a corn ethanol EROI of 0.156:1 = 1:6.4. Thus, making ethanol from corn is a negative energy balance process that consumes more than five-sixths of the energy invested.[93] The US economy would get six times as much usable energy from the same investment of fossil fuel energy if it was used to produce refined petroleum instead of being diverted to making ethanol and DDGS. Modern intensively-farmed corn, with its huge appetite for fossil fuel energy, is making a large net negative contribution to the nation's energy budget and thus working to increase rather than decrease fossil fuel demand. This is a trade we might justify for corn used as food, but it is an indefensible choice for corn converted into fuel.

What is true for corn ethanol is true for all cultivated crop biofuels. Natural gas and crude oil supply the vast majority of the hydrogen and carbon used to make fertilizers, pesticides, herbicides, farm machinery fuel, biorefinery process heat, the designer enzymes and bulk organic chemicals needed by some advanced processes, the hydrotreatment hydrogen gas discussed earlier, and a good portion of the electrical energy involved. The parasitic dependence of cultivated crop biofuels upon fossil fuels precludes any chance of them reducing dependence upon foreign oil, assuring domestic supply, or making prices less volatile. Without fossil fuels or a replacement source for massive quantities of hydrogen to make ammonia, all biomass yields—including food—will plummet toward what they were before Haber's discovery in 1909, with devastating consequences for the world.[94] Accelerating the use of fossil fuels by foolishly and wastefully using them to make much lower EROI biofuels brings any day of future fossil fuel scarcity that much closer and is completely counterproductive to every "clean" and "green" energy goal. Applying ammonia fertilizer to any crop intended for biofuel is an indefensible waste of energy.

Section 8: Energy and Economics

8.1. Markets and Price Volatility

Liquid biofuel prices are already as volatile as oil prices and track up and down with the international oil market.[95] The recent drought in the US midwest caused a corn price spike that already has forced the shutdown of many ethanol refineries and is jeopardizing fuel blending mandates.[96] Deriving fuel from farming does not liberate it from petroleum dependence or oil market price volatility, but rather increases price volatility by adding an additional linkage to global agricultural commodities markets. Energy security is reduced by choosing a primary energy source that has no proved reserves, but rather is created from scratch annually and is subject to floods, freezes, droughts, and blight. In the final analysis, biofuels are constrained by thermodynamics and the limits of photosynthesis to be niche fuels for those few in the world uniquely blessed with surplus fertile land and free water, and who have pre- or post-industrial power needs that can be met with low power density and unpredictably variable energy. This excludes the mining, manufacturing, electric utility, construction, and transportation sectors that are the *sine qua non* of modern civilization. Biofuels are simply not suitable to be national primary energy sources for developed nations, and less so for the exploding populations and meager budgets of developing nations. They are even less suitable for military forces, whose needs are more intensive and inflexible.

Energy security is reduced by choosing a primary energy source that has no proved reserves, but rather is created from scratch annually and is subject to floods, freezes, drought, and blight.

8.2. Peak Ethanol

Even before this year's drought, US corn ethanol production had been following a trajectory that should be familiar to disciples of Dr. Marion King Hubbert (see Figure 6).[97] Annual production totals of corn ethanol plot a perfect "Hubbert curve," rising from virtually zero in 1980 to peak this year at less than 15 billion gallons.[98] Dr. Hubbert was a petroleum industry geophysicist who in 1956 famously predicted what has become known as "Peak Oil." His prediction was based on observations of US crude oil production that had historically followed an exponentially increasing slope, but in 1952 hit an inflection point where the rate of growth started to slow. Hubbert fit a mathematical curve to the data and predicted that US oil production would peak between 1965 and 1970—and in 1970 his prediction came true. He explained his empirical observations with the rational theory that oil was a non-renewable, finite resource that gets progressively more difficult to find and extract as the amount is depleted. Rates of discovery would eventually slow and be overcome by the increasing difficulties of extraction, and production would peak when half of the extractable oil had been pulled from the ground.

However, if growing scarcity is all that drives a Hubbert curve, why do we see one for corn ethanol, a *renewable* resource? It is because there are additional factors—international competition, market share, carrying capacity, the decreasing energy-intensity of developed nations transitioning to services-based economies—that powerfully affect production of any fuel, renewable or otherwise. In the case of corn ethanol, Hubbert's peak would seem to indicate that supply has caught up with demand, and its subsidized surge to become a rival of gasoline is culminating at a value suspiciously coincident with the refinery blending market guaranteed by the EPA's Renewable Fuel Standard (RFS).[99] Interestingly, US oil production rebounded in the 80's in response to oil company capital investment in the 70's, and is rebounding again now in response to a surge of capital expenditures since crude prices started up in 2003. The lesson here for energy strategists is that there is danger in accepting one-dimensional explanations for observed behavior, and even more danger in relying exclusively on those simplistic explanations to make predictions. There is also a lesson for policy-makers about the inability of even massive subsidies to overcome underlying thermodynamic and economic weakness.

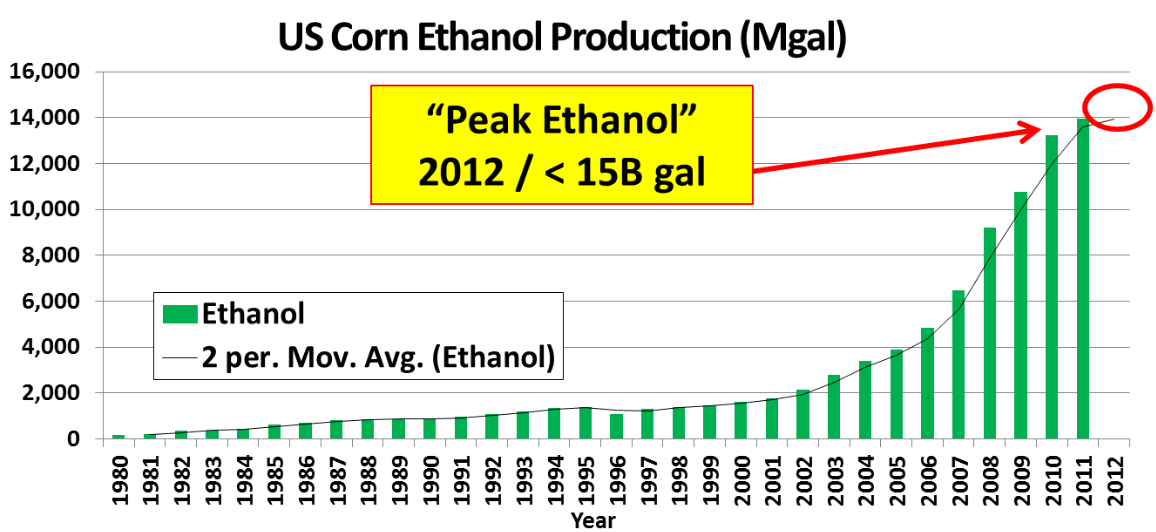

Figure 6. US Peak Ethanol

Section 9: The Real Cost of Biofuels

The huge gap between biofuel prices and petroleum fuel prices is directly linked to the similar disparity in their EROIs (compare Figure 1 and Table 1). High EROI fuels have lower costs and lower prices that allow both the fuel producer and the fuel consumer to profit because of low overhead and large margins. Low EROI fuels have higher costs and prices that leave both producer and consumer with little or no room to prosper.[100] Subsidies can mask the truth of EROI, but cannot change it. This is shown by the performance of biofuels enterprises when the subsidies run out, and by the transitory nature of the green jobs associated with those plants. According to a Washington Post analysis of DoE funding data, $17 billion disbursed by the federal government on green energy stimulus projects as of September 2009 had created less than 4,000 permanent jobs, with tens of thousands of temporary jobs disappearing once the money was spent.[101] Economies of scale work when margins are small but positive. However, when EROI is upside-down, scaling up just digs a bigger hole. In the case of new energy candidates such as biofuels, transition from research and development to deployment is harmful if it has not yet attained a lifecycle EROI of better than 6:1, and is not commercially viable unless it has attained an EROI competitive with the national average and other energy source alternatives (i.e., approximately 12:1 today per Figures 2 and 3). Below these thresholds, the energy candidate can only survive as a cash and energy parasite of government subsidies and higher-EROI energy sources.

9.1. The Military's Cost

One of the core goals of the DoD's new *Operational Energy Strategy* is to reduce military energy costs so that the Department can "shift resources to other warfighting priorities, and save money for the American taxpayers."[102] The civilian leadership of the US Navy is often heard quoting the statistic that a $1 rise in the cost of a barrel of oil increases annual fuel costs by $31 million.[103] Yet, the cheapest price the Navy has paid for any biofuel to date is $1,080.66 per barrel ($25.73 per gallon).[104] Since 2007, the military has spent $67.8 million on 1.35 million gallons of biofuel, averaging more than $50 a gallon or $2,100 a barrel, and costing the taxpayers $60 million more than if conventional fuel had been purchased (Table 1).[105] This does not include more than $47 million paid for pure research on alternative fuels. Based on the most recent government contract prices, a US military service secretary has the following

The cheapest price the US Military has paid for any biofuel to date is $25.73 per gallon.

Table 1: Department of Defense Fuel Purchases

Date	Contract	Vendor	Fuel	Gallons	$ Total	Per Gallon
DoD Biofuels Purchases						
Aug 2009	SP0600-09-D-0519	Sustainable Oils	Camelina JP-5	40,000	2,664,000	**$66.60**
Aug 2009	SP4701-09-C-0040	Solazyme	Algae F-76	20,055	8,574,022	**$427.53**
Sep 2009	SP0600-09-D-0518	Solazyme	Algae JP-5	1,500	223,500	**$149.00**
Sep 2009	SP0600-09-R-0704	UOP (Cargill)	Tallow JP-8	100,000	6,400,000	**$64.00**
Sep 2009	SP0600-09-D-0520	Sustainable Oils	Camelina JP-8	100,526	6,715,137	**$66.80**
Jun 2010	SP0600-09-D-0519	Sustainable Oils	Camelina JP-5	150,000	5,167,500	**$34.45**
July 2010	SP0600-10-D-0489	Sustainable Oils	Camelina JP-8	34,950	1,349,070	**$38.60**
Aug 2010	SP0600-10-D-0490	Sustainable Oils	Camelina JP-8	19,672	759,339	**$38.60**
Aug 2010	SP0600-09-D-0520	Sustainable Oils	Camelina JP-8	100,000	3,490,000	**$34.90**
Aug 2010	SP0600-09-D-0517	UOP (Cargill)	Tallow JP-8	100,000	3,240,000	**$32.40**
Sep 2010	SP4701-10-C-0008	Solazyme	Algae F-76	75,000	5,640,000	**$75.20**
Aug 2011	SP4701-10-C-0008	Solazyme	Algae F-76	75,000	4,600,000	**$61.33**
Sep 2011	SP0600-11-D-0526	Gevo	Alcohol to JP-8	11,000	649,000	**$59.00**
Sep 2011	SP0600-11-D-0530	UOP	Bio JP-8	4,500	148,500	**$33.00**
Nov 2011	SP0600-11-R-0705	Dynamic Fuels (Tyson, Syntroleum, Solazyme)	Tallow & Algae JP-5 Tallow & Algae F-76	100,000 350,000	12,037,500	**$26.75**
Feb 2012	N68936-12-P-0209	Albemarle	Cobalt n-Butanol to Jet Fuel	55	245,000	**$4,454.55**
Sep 2012	SP0600-13-D-0452	Amyris	Sugar F-76	18,000	463,140	**$25.73**
Sep 2012	SP0600-12-D-0561	Gevo	Alcohol JP-8	45,000	2,655,000	**$59.00**
DoD Synthetic Fuels Purchases						
Jun 2007	SP0600-07-D-0486	Equilon	Natural Gas to Aviation Kerosene	315,000	1,075,694	**$3.41**
Jun 2008	SP0600-08-D-0496	SASOL	Coal to Aviation Kerosene	60,000	225,000	**$3.75**
Jul 2008	SP0600-08-D-0497	SASOL	Coal to Aviation Kerosene	335,000	1,306,500	**$3.90**
Sep 2009	SP0600-09-D-0523	PM Group	Natural Gas to Diesel	20,000	140,000	**$7.00**
DoD Bulk Contract Conventional Fuel Purchases						
FY 2010	Various		JP-8 Jet Fuel	2,296M	5,201M	**$2.26**
			JP-4 / Jet A-1	1,249M	2,884M	**$2.31**
			JP-5 Jet Fuel	541.8M	1,175M	**$2.17**
			F-76 / Diesel	805.7M	1,816M	**$2.25**
			Motor Gasoline	70.7M	174.1M	**$2.46**
FY 2011	Various		JP-8 Jet Fuel	2,079M	6,478M	**$3.12**
			JP-4 / Jet A-1	1,246M	4,032M	**$3.24**
			JP-5 Jet Fuel	529.3M	1,572M	**$2.97**
			F-76 / Diesel	875.9M	2,590M	**$2.96**
			Motor Gasoline	59.0M	186.6M	**$3.16**

purchase options for jet fuel: $3.24 per gallon for conventional Jet A-1/JP-4 petroleum jet fuel on bulk contract, $3.90 a gallon to SASOL for coal-based synthetic, $7.00 a gallon to PM Group for natural gas-based synthetic, $26.75 a gallon to Dynamic Fuels for Tyson chicken fat-based hydrotreated renewable jet (HRJ), $34.90 a gallon to Sustainable Oils for camelina HRJ, $59.00 a gallon to Gevo for isobutanol-based HRJ, $61.33 a gallon to Solazyme for algae HRJ, $4,454.55 a gallon to Albemarle for converting Cobalt n-butanol to HRJ, $11,248.99 a gallon to Honeywell UOP for converting Gevo isobutanol to HRJ.

9.2. The Nation's Cost

The per-gallon price paid by the military for biofuels is only a fraction of the federal government's full cost. Federal officials profess grave concern at the volatility of oil prices, and economic forecasters cite statistics that a $10 rise in the price of a barrel of oil slows the US economy 0.2% and kills 120,000 jobs.[106] Yet, the federal government is voluntarily paying more than $10 a barrel in biofuel subsidies (Table 2).[107] DoE pumped $603 million into biofuel refinery construction in 2010 as part of $7.8 billion in annual biofuels spending.[108] Now the Navy, at the direction of the President and in partnership with DoE and the Department of Agriculture, is funding another round of new bio-refinery construction while scores of failed bio-refineries are on the market today in bankruptcy fire sales (a Google™ search of "biofuel bankruptcy" returns an eye-watering list).[109] In the more than five thousand years that humans have been producing ethanol as wine and beer and distilled spirits, it has always been realized that all the invested labor and energy made the resulting products far too precious to use their alcohol fraction as a fuel. Only urban folk in the modern era, blinded by the ubiquitous wealth of fossil fuel energy, could fail to see the negative energy balance of using distilled liquor as a fuel at the cost of all the wood or gas or oil fuel used to distill it. Ethanol has inherent limitations that have made it a perennial loser as an energy source throughout the ages, unable to win market share from wood, olive oil, whale oil, coal, kerosene, petroleum, or natural gas. After 6 years of huge subsidies and blending mandates and guaranteed markets in the United States since 2005, a joule of corn ethanol energy today is still more expensive than a joule of gasoline energy. The American Automobile Association reports as of December 2012 that the mpg-corrected price of E85 ethanol at the gas pump is 40 cents a gallon higher than premium gasoline.[110] Because of EPA-mandated blending of lower energy density ethanol in gasoline, consumers in 2010 paid $8.1 billion at the gas pump for energy that was not put into their tanks.[111] When added to the $6.1 billion in federal subsidies given out the by US Treasury and taxpayers as ethanol tax credits, the US paid a $14.2 billion premium in 2010 to displace 6.4% of its gasoline energy with ethanol—and the cheaper gasoline that was displaced was exported.[112]

After 6 years of huge subsidies, a joule of corn ethanol energy today is still more expensive than a joule of gasoline energy.

9.3. The Nation's Gain

A true primary energy source, like a true food source, cannot be subsidized. It must, by definition, yield many times more energy (and wealth) than it consumes, or else it is a sink, not a source. Critics of "big oil" often claim it is subsidized, but when both sides of the balance sheet are considered, the money is revealed to be flowing the other way. All federal subsidies and tax breaks for oil and natural gas in 2010, as officially tallied across all government agencies and reported to Congress, totaled $2.82 billion, equaling 45 cents per barrel produced domestically.[113] Against that outlay, the federal government collected $56.1 billion in oil company corporate taxes and excise taxes on retail gasoline and diesel, equaling $9.01 per barrel—a 2,000% return.[114] State and local governments also collected similar shares in taxes and fees as well. It is not by subsidies, but rather by the merits of EROI and energy density and power density, and in spite of heavy taxation and fierce competition with other energy alternatives, that oil and gas have grown to dominate the global energy economy. Oil and gas are true primary energy sources that nourish rather than starve governments and economies. Global oil and gas is a $3.8 trillion industry that fully subsidizes 10 *rentier* petro-states and partially subsidizes the economies of 70 more oil exporting nations.[115] Just in the United States today there are 536,000 active crude oil wells, 504,000 active natural gas wells, dozens of continent-spanning pipelines, a colossal interstate highway system, 17 million barrels-per-day of refining capacity, 160,000 gas stations, and a $1.5 trillion fraction of the global oil and gas industry that have all been funded out of oil and gas EROI margins. The 1.5 trillion-dollar US share of the global oil and gas industry comprises 10% of the $15 trillion US economy.[116] Coal also has a high EROI, and together, fossil fuels provide 82% of US primary energy.[117] That fraction is a good approximation for the fossil fuel portion of the energy invested in making anything manufactured in the United States—including both food and biofuel.

Table 2: US Federal Government Energy Subsidies in 2010

US Federal Government Energy Subsidies in 2010			
Energy Source	***Federal Subsidies ($M)***	***Domestic Production (million barrels of oil equivalent)***	***Subsidy per barrel of energy produced***
Coal	1,358	3,793	$0.36
Oil & Gas	2,820	6,229	$0.45
Hydro	216	437	$0.49
Nuclear	2,499	1,451	$1.72
Geothermal	273	36	$7.63
Bio-mass/fuel	7,761	747	$10.39
Wind	4,986	159	$31.39
Solar	1,134	22	$52.30
Total	***21,047***	***13,921***	***Average = $1.63***

Section 10: Power Density and Capacity Limits

If EROI and price were not fatal enough, the question of ultimate capacity must also be answered. Land is a finite national resource with many competing uses. A recent European meta-study of 90 other studies found that only one-fifth of the world's energy demand could likely be met by biofuels without removing meat from the human diet or making massive land use changes beyond the 296 million acres that already must be added for additional food crops before 2050.[118] This is ultimately because biofuel production is a terribly inefficient use of land. This can best be illustrated with *power density*, a key metric for comparing energy sources.

10.1. Energy Sprawl

The 70 gallons of biodiesel per acre of soy and 500 gallons of ethanol per acre of corn are amazing agricultural achievements, but are dismal in terms of power density, and work out to be only 0.069 W/m^2 and 0.315 W/m^2 respectively. While corn is 4.5 times better than soy, it is a factor of 3 below wind (1.13 W/m^2), 19 times worse than PV solar (6.0 W/m^2), and 300 times worse than the 90 W/m^2 delivered by the average US petroleum pumpjack well on a 2-acre plot of land.[119] Thirty square meters of today's cheapest PV solar panels can capture the same amount of energy per year as is in the ethanol from 10,000 square meters (2.5 acres) of cultivated switchgrass.[120] This is coincidentally about the same amount of land the average American family would require as biofuels pasture for each of their cars. Alternatively, that land could sustainably grow crops to feed 20 vegans, or the crops and livestock to feed 2.5 meat-eating humans.[121] To replace the 28 exajoules of energy that the U.S. uses every year just for cars and trucks and airplanes would require more than 700 million acres of corn. This is 37% of the total area of the lower 48 states, more than all 565 million acres of forest, and more than triple the current amount of annually harvested cropland. Soy biodiesel would require 3.2 billion acres—one billion more than all U.S. territory including Alaska. Oil palm biodiesel yields are reported to be as high as 640 gal/acre (6,000 L/ha), which exactly doubles the power density of corn ethanol, but still falls far short of wind and solar power. As hinted earlier, algae biodiesel has the highest potential power density of any biofuel, but the best case predicted to ever be achievable at some date in the distant future, as

Algae biodiesel has the highest potential power density of any biofuel, but its predicted best-case future performance is equivalent to today's solar panels.

limited by physical laws and laboratory-perfect conditions, is 6.42 W/m^2—equivalent to what is produced today with PV solar panels at the solar farm on Nellis Air Force Base.[122] Figure 7 contrasts the land area of oil field, solar farm, wind farm, and corn field needed to replace the 2,000 MW of power produced by the San Onofre Nuclear Generating Station in Oceanside CA.

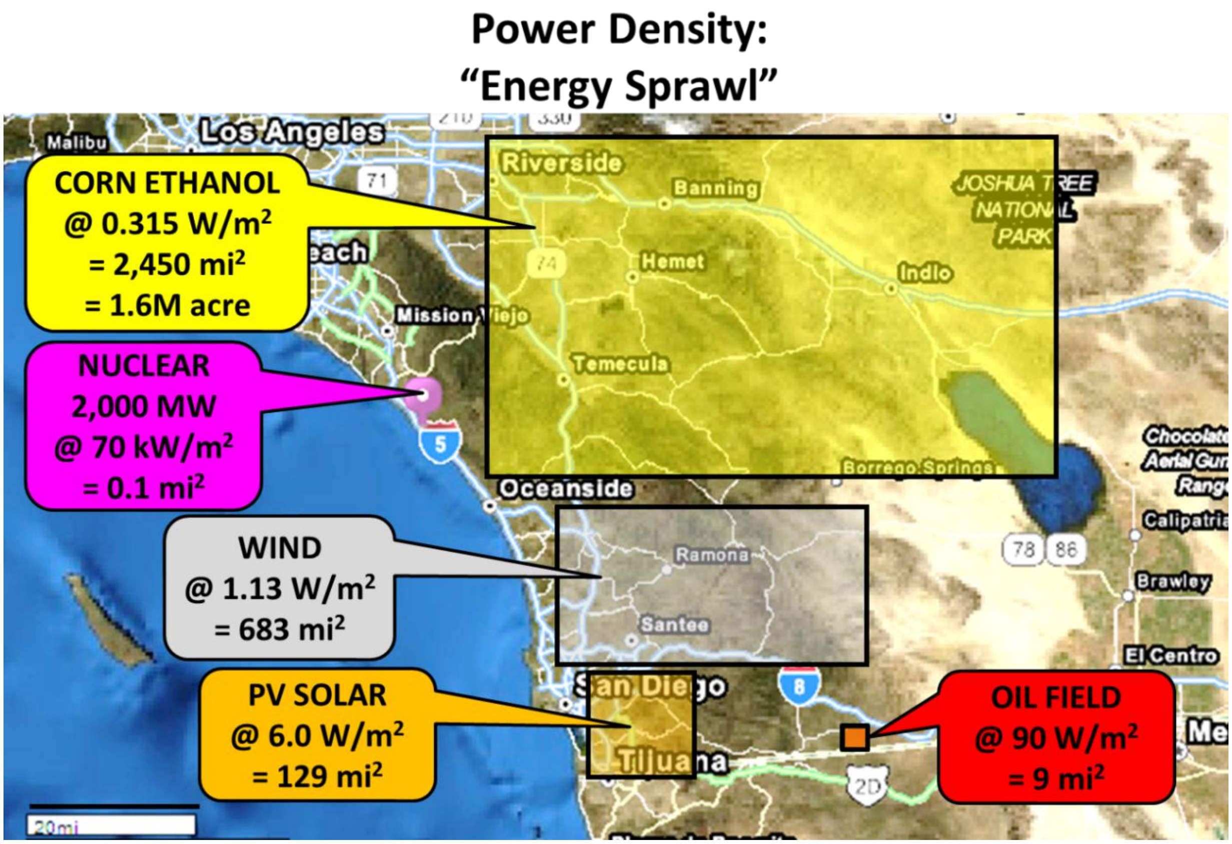

Figure 7. Power Density and "Energy Sprawl"

10.2. Green Grabbing

The USDA and DoE have explored the technical feasibility of channeling one billion tons of US biomass a year toward biofuels production.[123] However, their work discounts two very significant facts that undermine the positive conclusions. The first is that large amounts of cellulosic forest floor debris and cultivated crop residue stalks and leaves are not truly waste that can be harvested for fuel, but are still vital parts of the ecosystem that need to be left in place to conserve soil and water. These residues cycle soil nutrients, enhance the efficiency of fertilizer and irrigation, and feed soil bacteria and fungi essential to plant growth. Whatever fraction of biomass is removed from an ecosystem or farmer's field instead of being left to compost and recycle is a loss that must eventually be replaced or the soil will be depleted. The thermodynamic checkbooks of energy and mass must be balanced.

The second fact is that, in a world of globalized economies, rich nations are not limited to their own territory. The high expense and environmental protection of land in the United States and developed nations leads energy farmers to look for cheaper land in less developed countries.[124] The United States and European nations are primarily pursuing offshore land indirectly through joint ventures, such as Blue Sugars' joint venture with Petrobras where Brazilian sugarcane bagasse feedstock was grown overseas and shipped to the United States for processing.[125] However, around the world today unscrupulous governments are confiscating land from villagers and burning forests wholesale to make way for lucrative biofuel plantations.[126] There is well-documented "green grabbing" of land in Latin America and Africa and Asia for cheap acreage and water rights needed for cash crops. A 2010 World Bank analysis revealed that wealthier countries including Saudi Arabia, South Korea, and China have already bought or leased more than 27 million acres of foreign land and water rights for remote cultivation of food, industrial, and biofuel crops. The chief locations for such appropriations are Sudan, Mozambique, Liberia, and Ethiopia, where governments are not protective of citizen land rights and more than 12 million persons are living hand-to-mouth on aid from the UN World Food Program.[127] This negative impact on rural native people is not likely to change as almost half of the world's potentially available arable land not already in food production is situated in only seven countries: Angola, Argentina, Bolivia, Brazil, Colombia, Democratic Republic of Congo and the Sudan.[128] The truth is that, even at today's small scale of production, biofuels' huge appetite for land already puts wealthy nations in significant and direct competition with global food production and the interests of the hungry. Food must and will eventually win this competition because there is not enough suitable land for both.[129]

Biofuels' huge appetite for land already puts the wealthiest nations in global competition with food production for the hungriest.

Section 11: Biofuels versus the Environment

Despite claims of reduced GHG and pollution emissions for biofuels, the reverse is now becoming apparent. Biofuels have roughly the same tailpipe or flue gas emissions as conventional fuels, but until recently they automatically earned "green" and "reduced emissions" badges through simplistic accounting tricks that assumed all their carbon was recycled from the atmosphere and also largely ignored the pollutants.[130] New more thorough studies that consider the full fuel creation and combustion lifecycles (as in Figures 3 and 4 above) are now showing cultivated liquid biofuels to be more damaging to the environment and causing the release of more CO_2 and other greenhouse gases and pollutants per unit of energy delivered than fossil fuels.[131]

11.1. Air and Water Pollution

Biofuels can be more threatening to the environment in some respects, and nowhere has this been more conspicuously ignored than with ethanol. The overall environmental impact and social costs of adding ethanol to gasoline as an oxygenate have been shown to be negative.[132] The only reason for oxygenating fuel is to reduce carbon monoxide emissions, yet ethanol does nothing to improve the carbon monoxide emissions of any US car built since 1993.[133] Like the MTBE oxygenate additive it replaced,[134] ethanol threatens water quality and increases the environmental hazard of spills because ethanol-blended gasoline is more water-soluble and leaches through the soil faster than straight gasoline. The EPA was presented with evidence in 1999 that ethanol may extend gasoline soil and groundwater pollution plumes 25-40% and inhibit natural gasoline biodegradation in the soil, but as yet the agency has established no national monitoring for environmental ethanol contamination as it did for MTBE.[135] Ethanol blending also makes open water contamination more difficult to clean up because more of the spilled fuel mixes with the water instead of floating on the surface and evaporating.[136] Ethanol unquestioningly reduces the fuel economy of every gasoline vehicle in direct proportion to its blending ratio,[137] increases emissions of some smog precursors, and requires a standing waiver from the EPA for their own air quality standards.[138] A blue ribbon panel of experts commissioned by the EPA in 1999 recommended discontinuing the use of all oxygenates in gasoline.[139]

11.2. Climate and CO_2

The most important change in the new lifecycle studies is the proper accounting of land use change driven by biofuel cultivation such as converting forests to energy crop fields by burning. This widespread practice has been accelerated around the world by biofuels agriculture, and is releasing centuries of carbon sequestered in forest biomass back into the atmosphere from these natural carbon sinks. Such burning strikes a double blow because it also destroys a dense living biome with a huge perpetual appetite for CO_2. It is now calculated that large-scale conversion of virgin land to biofuel production has already released and continues to release so much CO_2 into the atmosphere that it may be centuries before this surge can be offset by the recycled carbon in the resulting biofuels, if at all. The continued burning of millions of acres of forest and peat lands to make room for oil palms has made Indonesia the world's third highest producer of CO_2 after the United States and China.[140] The additional global warming effects of land cultivation for biofuels are addressed in the nitrogen discussion below.

The principal efforts for halting global warming are currently directed at reducing CO_2 emissions and sequestering CO_2 out of the atmosphere. While developed nations with post-industrial economies are making some progress in CO_2 emission reductions by switching to lower carbon fuels, improving energy efficiencies, and shifting toward less energy-intensive service-oriented economies, these are dwarfed by increased releases from developing countries such as China, India and Indonesia.[141] The overall mass of humanity is still inexorably increasing its energy consumption as electricity and industry and modern amenities spread to the underdeveloped world, and global CO_2 emissions are rising 2-3% per year. There is no realistic prospect, short of decimating the human population, of reducing the 35 gigatons of CO_2 produced by civilization each year.[142] Just halting the annual increase would require converting 2-3% of global electrical power capacity to zero-emission plants each year without releasing any CO_2 in their construction.[143] That equates to 300-450 GW of power generation capacity, which is approximately half of US total capacity, and is tantamount to magically commissioning one new nuclear power plant every day of the year for decades to come.

While man-made carbon capture is still in its infancy, it is clear that there are finite limits and environmental risks to underground and deep-ocean storage. The only truly sustainable approach for the very long term (centuries) is to capture CO_2 the way nature has since the dawn of life, in the green biomass of plants and algae. Very counterproductive to that goal is large-scale burning of plants as fuel. The challenge of mitigating global warming is to increase the green carbon-inhaling biosphere to balance man's carbon dioxide-exhaling civilization. Maintaining living orchards and no-till grain fields with perennial biomass is a better approach for GHG emissions and for solving the challenges of the looming food crisis than converting vast tracts of land to biofuel commodity crops and harvesting even the crop residues normally left to preserve nutrients in the soil. One key pillar of a sound global warming mitigation strategy should be growing huge new volumes of biomass *and not burning them*.

One key pillar of a sound global warming mitigation strategy should be growing huge new volumes of biomass *and not burning them*.

11.3. The Nitrogen Problem

Nitrogen is on a path to becoming even more regulated than CO_2 because of the ecological damage it can cause. Nitrogen from fertilizer runoff is implicated in acid rain, in the nitrate poisoning (eutrophication) of one-third of US streams and two-fifths of US lakes, and in human disease.[144] Increased agriculture for biofuels has multiplied this challenge. Nitrous oxide (N_2O) is a gas released by ammonia-based fertilizer production and use. One N_2O molecule has 298 times the global warming potential of one molecule of CO_2.[145] N_2O currently contributes 8.4% of global warming radiative forcing, and its share is growing.[146] It is now also the top ozone-depleting compound being released into the atmosphere.[147] Between 1% and 5% of the nitrogen in ammonia fertilizer applied to cultivated crops escapes to the atmosphere as N_2O.[148] A host of new studies that consider both land use change and nitrogen effects conclude it is better for the climate and the environment to stick with conventional fuels than to put new land into cultivation for biofuels.[149] Section 526 of the *Energy Independence and Security Act of 2007* (EISA) specifies that the lifecycle GHG emissions of any alternative or synthetic fuel purchased by the US government must be less than or equal to such emissions from the equivalent conventional fuel produced from conventional petroleum sources.[150] In light of recent research, and in the interest of curbing global warming, the US Government should reexamine all Section 526 certifications so far given for biofuels and blends. Any that do not consider the full lifecycles including land use change, that neglect N_2O or any other GHG emissions, or that do not properly compare opportunity cost with conventional fuels should be invalidated.

Section 12: The Competition of Fuel and Food

In 2008, world grain market prices tripled, mirroring and surpassing the spike in global oil prices, and proving the linkage between food Calories and energy calories in the modern world. Grain prices to the poorest consumers increased as much as 50%, driving 8% more of Africa's population toward hunger and raising the world's undernourished population to approximately 850 million.[151] Today's market prices are still double what they were in 2007. Various studies of the 2008 food price spike surveyed by the World Bank have attributed as much as 70% of the increase in corn prices and 100% of the increase in sugar prices to global diversion of food to biofuels.[152] A union of the world's preeminent food and assistance agencies including the World Food Program and the Food and Agriculture Organization of the United Nations has formally called for all G20 nations to drop their biofuels subsidies and mandates because of the impact they are having on driving up food prices around the world.[153] It is a myth to think that non-food biofuel crops do not compete with food. Labels such as "Gen2" or "Advanced" can only serve as Orwellian attempts to hide the truth and assuage investor consciences. That fact is that every cultivated crop—food or non-food—competes with every other cultivated crop for finite resources including water, land, agrichemicals, farm equipment, transportation, financing, etc. Putting more demand on these resources raises prices for everyone. Biofuels are becoming a huge threat to global food security, and thereby to global stability—a fact that should shape any military or political energy strategy. Many analysts now looking at the "Arab Spring" phenomenon recognize that, underlying the very real political aspirations of movements such as the revolution in Tunisia, there was outrage at skyrocketing food prices. What first began as riots in Egypt due to the government no longer being able to afford to subsidize the price of bread became a hot-blooded revolt and *coup*.

Every cultivated crop competes with every other cultivated crop for finite resources including water, land, agrichemicals, farm equipment, and financing.

12.1. The Looming Global Food Crisis

As the global population sprints toward 9 billion by 2050, there are 140,000 more mouths to feed every day. Food grain consumption is growing at 40 million tons per year.[154] Yet, because of enormous market-distorting subsidies, the United States today produces more corn for ethanol than for food or cattle feed.[155] For decades past, America had surplus food crop capacity and used it to rescue other nations from famine. In 1965 President Lyndon Johnson's administration shipped one-fifth of the US wheat crop to India during a devastating drought.[156] With slack land now being consumed by biofuels production, a drought such as the one that destroyed 40% of Russia's grain crop in 2010 would be devastating to national security—particularly because both food and fuel would be simultaneously affected. The negative consequences of biofuels upon food crop production have been understood by the US government since a blue-ribbon panel of scientists appointed by the newly formed DoE rejected gasohol for this and other sound reasons in 1980.[157] Twenty-five years later in 2005, politics trumped science with the imposition of US ethanol blending mandates and corn ethanol subsidies that even Al Gore now regrets—and the world is reaping what we have sown.[158] If our greater interest is truly global peace and security, US farmers should be out of the fuel business, and instead looking to increase food production to fill commodity and direct export orders with famine-wary nations in the overstressed global food market.

12.2. The Mineral Problem

Potash and phosphate are critical plant macro-nutrient minerals which must be provided in large quantities for both food and biofuel cultivation. The United States currently imports 85% of its potash supply.[159] In 2011 the global price of potash doubled, sending fertilizer prices skyrocketing.[160] In 2010 America imported 13% of its phosphate, and 90% of this came from Morocco, an Islamic kingdom of the North African Maghreb region that is a growing stronghold of Al Qaeda. In 2011, phosphate prices jumped $60 per ton. Replacing US transportation fuel with algae biodiesel would require about 88 million more tons of phosphate rock to be mined a year[161] compared to current US production of 28.4 million tons and total global production of 191 million tons.[162] While there is a loud chorus of pundits preaching doom about the price volatility of oil and US dependence upon unstable Persian Gulf nations (source of 13% of US crude in 2011), few are those who recognize how susceptible US agriculture is to foreign economic influences. Basing our transportation energy supply on agriculture via biofuels only exacerbates this risk. It is critically important for energy strategists and policy makers to realize that exchanging a fuel dependent on foreign crude oil imports for a fuel dependent on foreign potash and phosphate imports does not improve national security. In fact, it puts both food and fuel in jeopardy of a single embargo.

Exchanging a fuel dependent upon foreign oil imports for a fuel dependent upon foreign mineral imports does not improve national security.

12.3. The Water Problem

The final knife in the chest for biofuels is their water demand. "Water footprint" is the term for how much fresh water is consumed or rendered unusable by a particular activity. This can happen by evaporation, by removal to inaccessible parts of the ecosystem, and by contamination with chemicals such as industrial discharges or crop fertilizer runoff. Water use also represents a dimension of competition with food agriculture, but it is even more urgent and fundamental in its own right. While "peak oil" continues to be elusive (global petroleum production and proved reserves both set new record highs in 2011,[163]), "peak water" has already arrived for much of the world. One third of all countries are today considered "water poor." Two of every five people do not have enough water for basic sanitation and nearly one in five do not have enough to drink.[164] Many scientists and economists today observe falling water tables and depleting aquifers due to over-pumping (including the massive Central Valley and High Plains aquifers in the United States) and predict this will expand to a global water crisis by 2030.[165]

Much of the Middle East and a growing number of other nations including China, Japan, Australia and Spain are now dependent upon desalination of seawater for a significant fraction of their fresh water needs.[166] To put this dependence in perspective, consider that the USS Carl Vinson, a Nimitz class aircraft carrier, can desalinate 400,000 gallons of water a day with its nuclear reactors, and recently used that capacity to assist Haiti with fresh water after its devastating earthquake.[167] The current desalination demand of the world exceeds 78 million cubic meters per day with 11% annual growth.[168] That equates to 51,500 aircraft carriers worth of desalination capacity with 5,600 more being built each year. Saudi Arabia in 2008 quietly abandoned a 40-year program to become self-sufficient in food production via huge state-of-the-art desert farms and greenhouses. The reason was the decreasing level of their "fossil water" aquifers and the growing expense of water desalination. Saudi Arabia's ground water production peaked in 1992, and today the country relies on desalination for 70% of its household water.[169] There is a growing direct economic convertibility in the world between liters of fuel and liters of water. Saudi Arabia is now willing to spend one liter of ethanol equivalent energy in crude oil to desalinate 200-300 liters of water in their massive Shoaiba facility.[170] How do those economics mesh with biofuels?

12.4. Water and Biofuels Don't Mix

Conventional gasoline has a water footprint of 2.3 to 4.4 liters of water per liter of ethanol equivalent energy (L/L) including water injected into the ground for enhanced oil recovery and water used in refining.[171] In contrast, global averages for biofuels range from sugar beet ethanol (1,388 L/L) to corn ethanol (2,570 L/L) to soy biodiesel (13,676 L/L) to rapeseed biodiesel (14,201 L/L) to jatropha biodiesel (19,924 L/L).[172] Current state of the art for installed seawater desalination plants ranges from 126 to 970 liters of water per liter of ethanol equivalent energy.[173] So, under absolute best case circumstances, sugar beet feedstock cannot produce enough ethanol fuel energy to desalinate enough water to grow a replacement crop, let alone provide leftover ethanol as fuel. Biofuels' huge dependence upon water means they are not truly a renewable fuel in any location where water is being depleted. *Not one biofuel crop is renewable in desalinated* *seawater*. Under the President's recently published update to *Executive Order 13603* that specifies responsibilities under the *Defense Production Act* of 1950, the Secretary of Defense is now responsible for the US water supply.[174] That should cause reflection regarding DoD's promotion of biofuels. When Saudi Arabia and a third of the world are willing to spend a liter of fuel for less than 1,000 liters of water, how long can others get away with spending 10,000 liters of water or more for one liter of biofuel?

Biofuels are not renewable in any location where water resources are being depleted.

12.5. The Advent of the Global Water Market

The Chairman of Nestle Foods is one among a growing host who believe that ecological and population stresses on water will only be balanced by sound water management when water becomes a market commodity instead of a free utility.[175] According to Citigroup's chief economist, water will become "the single most important physical commodity based asset class, dwarfing oil, copper, agricultural commodities and precious metals."[176] At some point, governments will no longer be able to afford to subsidize water, just like many have had to abandon subsidizing wheat in the past two years, and will have to pass the costs on to their industries and populations. If they have not already succumbed to other factors, the establishment of a regional or global water market will be the death knell for biofuels. This is another eventuality with dramatic global implications that energy strategists should be anticipating.

Section 13: Can a Technology Breakthrough Save Biofuels?

Ultimately biofuels are limited by the sun. If they rely exclusively on the sun's energy and organic soil nutrients to make biomass without adding fossil fuel energy, the EROI can be high enough, but the power density will be far too low even with maximum theoretical photosynthesis performance. If yield is boosted with fossil fuel energy, fossil fuel use increases, biofuel EROI plummets and drags overall EROI with it, power density is still too low, and civilization ends up even more starved for power. The way out of this dilemma is to have a plentiful supply of hydrogen from a non-fossil fuel source, and the only prospect for doing this in sufficient quantity is to electrolyze hydrogen from water using nuclear power. However, if we had such a surplus of nuclear power electricity and hydrogen, we would use these directly for energy and fuel and not mess around with the inefficient middleman of biomass. This litany is the inescapable Catch-22 of biofuels.

Converting natural gas hydrocarbons into ammonia fertilizer and then into the carbohydrates of plant biomass is a sequence of transformations that irreversibly consumes significant usable energy in each step. That loss of energy can be justified if the crop being grown is food, and is of greater need than the energy used to grow it. However, completing the circle by converting that plant's carbohydrate biomass back into hydrocarbons for fuel makes the whole process a futile analog of the perpetual motion machine. Improvements in technology can reduce the percentage of energy lost in each conversion, but cannot eliminate it. Any wood, grass, peat, bagasse, coal, natural gas, or oil will deliver much more benefit to civilization if used directly and efficiently as fuel by a consumer whose needs are compatible with its limitations, rather than by using its energy to make biofuels. As long as the preponderance of ammonia and free hydrogen and organic compounds used in agriculture are derived from petroleum and natural gas, cultivating biofuels will defy all logic. They can never be cheaper than fossil fuels while fossil fuels comprise the bulk of the energy invested to make them.

Converting fossil fuel hydrocarbons into plant carbohydrates and then back into hydrocarbon fuels is a futile attempt at perpetual motion in chemistry.

Section 14: Conclusions and Recommendations

Imagine if the US military developed a weapon that could threaten millions around the world with hunger, accelerate global warming, incite widespread instability and revolution, provide our competitors and enemies with cheaper energy, and reduce America's economy to a permanent state of recession. What would be the sense and the morality of employing such a weapon? We are already building that weapon—it is our biofuels program. We need to quit the moonshine and face the sober facts. The DoD should pivot away from biofuels in its own energy strategy and the federal government should recraft its overall national energy strategy to be compatible with physics and biology and economics for the sake of national and global security. This revised strategy must acknowledge that:

1. The threshold test for any candidate for primary energy source or fuel is demonstrating the ability to bootstrap itself up in scale and energy productivity without outside assistance. This is equivalent to having an EROI greater than 1:1. The successful candidate will eventually have to do far better than this: it must surpass 6:1 to be minimally useful to modern civilization and match or exceed the 12:1 US average EROI to be commercially competitive. A true 21st century fuel must deliver enough energy profit to build up its own production and distribution infrastructure just as coal and oil did in the previous two centuries. Such a test quickly reveals that the quality of energy measured in such things as EROI, energy density, power density, and *dispatchability* (controllability of energy delivery location, timing, and rate)[177] matter just as much as total power output. Until this level of performance is achieved, the energy candidate is a research and development experiment that cannot survive without subsidy. Conversely, any energy candidate that is receiving a net subsidy is by definition not an energy source. The US government should not push to commercialize any energy candidate until it has demonstrated lifecycle performance at competitive EROI without subsidy.

2. Biomass is critically limited by the sun and biology to insufficient power density and energy density to be a viable national primary energy source or transportation fuel feedstock. Unfertilized biomass from unmanaged land (e.g., firewood) may offer some benefit to niche consumers who can abide its limitations, but it should be consumed as-is, without wasteful attempts at transformation to a liquid. Regardless of form, it simply cannot support the industrial, commercial, and transportation sectors of modern economies.

3. The best EROIs of today's cultivated liquid biofuels fall between those of agrarian Rome and the Stone Age. They would be even lower if not for stealing fossil fuel energy throughout their lifecycle. None have any prospect

of simultaneously attaining the 6:1 threshold EROI necessary to marginally support a modern civilization, let alone 12:1 to match the current US average, while also achieving the power density and energy density necessary to supplant a significant fraction of the national transportation fuel supply.

4. Current US biofuels policy is increasing ecological damage and GHG emissions due to destructive global land use change, harmful agrichemical side-effects, and the accelerated consumption of fossil fuel. This is the exact opposite of "clean and green." The US military and federal government need to rationally and authoritatively define "renewable," "sustainable," and "green," and enforce empirical standards for meeting these criteria based upon rigorous lifecycle and opportunity cost analyses.

5. Recent research indicates that cultivated liquid biofuels are not renewable in water, are not green in ecological footprint, and are not sustainable in energy balance. EISA Section 526 Certifications performed without the benefit of this research and without full consideration of land use change and all GHG emissions should be invalidated and redone.[178]

6. The best case power density predicted to ever be achievable for any biofuel is already attained by today's PV solar panels. The US government should cease subsidizing biofuels and instead offer prizes for milestones in improved PV solar panel performance.

7. Biomass is an inefficient middleman between solar energy and fuel. A better approach is to bypass the creation of biomass completely and directly synthesize liquid fuel from sunlight. The US government should cease funding biofuel research and instead offer prizes for milestones in direct fuel photosynthesis.[179]

8. Refined petroleum is currently unbeatable as transportation fuel, and it is to civilization's net loss if it is used to process biomass into inferior fuels. Doing so represents a huge opportunity cost and accelerates the arrival of any day of future petroleum scarcity.

9. The diversion of any fossil fuel energy to boost biofuel yields (in the form of synthesized ammonia or sugar nutrients, pesticide or herbicide, farm equipment fuel, transportation fuel, processing plant energy, distillation energy, enzyme and organic chemistry feedstock, or hydrotreatment hydrogen) is wasteful of energy, undermines the very purpose of alternative fuels to replace fossil fuels, and reduces the overall EROI of the nation. The federal government should prohibit the use of fossil fuel-derived fertilizers and agrichemicals on energy crops.

10. Use of fossil fuel energy to accelerate food crop growth can be justified as a necessary trade, but the dependencies of agriculture upon external energy sources need to be explicitly quantified to improve the efficient operation of

both the food and energy realms. Those in the agricultural arts and sciences should begin to account for energetic hydrogen from ammonia, urea, and sugar as carefully as they currently account for nitrogen, phosphorus, potassium, and carbon. Farmers who recognize the fertilizing power of hydrogen may shift toward fertilizers with greater hydrogen-to-nitrogen ratios and help ease the blights of nitrate runoff and eutrophication that result from over-application of nitrogen.[180]

11. Government energy policies that restrict domestic development of a nation's highest EROI energy sources and fuels such as hydropower, coal, natural gas, and petroleum are tantamount to caps on thermodynamic efficiency, economic health, and international competitiveness. Conversely, the nations that pursue the highest EROI energies will have the greatest potential to grow their economies and have every prospect of advantage over countries limited to lower EROI sources. The government should end subsidies and market-distorting policies that encourage low-EROI energy sources over high-EROI sources.

12. Global air and long-haul transportation are currently very dependent upon liquid hydrocarbon energy, and it is unlikely that physically superior combustion fuels will be found. If the world runs out of fossil fuels without an alternative source for massive amounts of energetic hydrogen and carbon, civilization also immediately runs out of transportation fuel. To the extent that oil and gas are judged to be running out, the government should ensure there is excess electrical capacity from non-oil and gas power plants to electrolyze sufficient quantities of hydrogen from water for transportation fuel purposes.

13. Global food production is currently very dependent upon fossil fuel energy. If the world runs out of fossil fuels without an alternative source for massive amounts of energetic hydrogen, civilization also immediately runs out of both biofuels *and food*. To the extent that oil or gas are judged to be running out, the government should ensure there is excess electrical capacity from non-oil and gas power plants to electrolyze sufficient quantities of hydrogen from water for food agriculture purposes.

14. The best use of agricultural land and water is growing food for one's own country and a surplus to cover global shortages. This has been before and again can be a significant US contribution to international security and stability.

15. The technologies most in need of Manhattan Project attention by our global security strategists and national scientific laboratories at this very minute are sustainable water production and food agriculture to support the 9 billion people of 2050. The US government should cease funding biorefinery construction and instead offer prizes for milestones in food production and water desalination efficiencies.

16. CO_2 is not the only GHG. Agriculture is the leading producer of N_2O and a major producer of CH_4, which together comprise more than 26% of current total atmospheric GHG effects.[181] The US government should levy any caps or taxes equitably across all greenhouse gases in proportion to their global warming potentials. Any per-ton penalties imposed on CO_2 should be levied against CH_4 at 69 times the rate, and against N_2O at 298 times the rate to reflect their relative per-ton global warming potentials.[182]

17. The price of oil, like that of any other global free market commodity, is volatile and subject to war, politics, and speculation. However, global markets, on average, deliver better prices than regional or local markets. Biofuels are not only subject to energy market forces, but are also subject to agricultural market forces and the vagaries of the weather. Biofuel prices are already proving to track with oil prices and to match their volatility, and it is likely to get worse once subsidies and guaranteed markets are abolished. Regardless of this, it is logically indefensible to buy a $30.00 per gallon fuel over worries about the price volatility of a $3.00 per gallon fuel.

18. Military dependence upon petroleum is less of a national security risk than dependence upon biofuels. Petroleum is produced in more than 80 countries, global proved reserves are over 1.6 trillion barrels and growing, and a century and a half of capital investment has made petroleum fuels available in every major port and airfield on Earth. In contrast, liquid biofuels derive 80% or more of their energy content from fossil fuel and go away if fossil fuels go away; are subject to interruption by weather events such as drought, freeze, and flood; have zero proved reserves and must be made season-by-season; are encumbered with the price volatility of both the energy and agricultural markets; are neither globally standardized nor globally available; and are money sinks for a federal government $16 trillion in debt.

Modern civilization has progressed to the point where its underlying technology often operates according to counterintuitive laws and at scales of size, complexity, and interconnectedness that surpass common human experience. Sound decisions cannot be made based solely upon popular opinion, personal opinion, orthodox worldviews, or even common sense. Wise leaders must have "uncommon sense" founded upon a broad and deep education, and keen insight achieved through thorough study of the science and the empirical evidence of the issue at hand. National energy strategy is nothing less than national survival strategy. Those who would craft such strategy or advise policy-makers need to be well-grounded in chemistry, thermodynamics, biology, and economics, so they might discern the difference between promising avenues of research and perpetual motion schemes that defy physical laws and waste our nation's time and treasure. Trying to biofuel our way to energy independence is like medieval physicians trying to bleed their patients back to health. It is time to stop the bleeding.

Notes

[1] Öko-Institut (Freiburg im Breisgau, Germany), and IEA Bioenergy Programme. The Bioenergy and Water Nexus. [Nairobi, Kenya]: United Nations Environmental Programme, 2011.

[2] See 1. James S. Kus, "The Chicama-Moche Canal: Failure or Success? An Alternative Explanation for an Incomplete Canal," *American Antiquity* 49, no. 2 (April 1, 1984): 408-415; and 2. Charles Mann, *1491: The Americas Before Columbus* (London: Granta, 2006). It is debated by archaeologists how much of the Chimu canal failure is attributable to faulty topographical surveys, faulty engineering, or shifting fault lines from a landscape that was geologically active in the past.

[3] Sherrard and Kressman. "Review of Processes in the United States Prior to World War II." Industrial & Engineering Chemistry 37, no. 1 (January 1, 1945): 5–8. http://pubs.acs.org/cgi-bin/doilookup/?10.1021/ie50421a003.

[4] "The Early Days of Coal Research." Department of Energy, November 13, 2012. http://fossil.energy.gov/aboutus/history/syntheticfuels_history.html.

[5] See 1. "Historical Price Viewer." Energy Information Administration. http://www.eia.gov/forecasts/steo/realprices/; and 2. Pimentel et al. *Report of the Energy Research Advisory Board on Gasohol*. Gasohol Study Group, April 29, 1980.

[6] Sheehan et al. *A Look Back at the US Department of Energy's Aquatic Species Program: Biodiesel from Algae*. Vol. 328. National Renewable Energy Laboratory, 1998.

[7] See 1. Bartis et al. *Alternative Fuels for Military Applications*. RAND National Defense Research Institute, 2011. http://www.rand.org/pubs/monographs/MG969.html; and 2. Dina Fine Maron. "Biofuels of No Benefit to Military -- RAND." New York Times, January 25, 2011. http://www.nytimes.com/cwire/2011/01/25/25climatewire-biofuels-of-no-benefit-to-military-rand-11643.html.

[8] See 1. Bartis et al. Project Air Force (U.S.), and RAND Corporation. *Promoting International Energy Security*. Santa Monica, CA: RAND, 2012. http://www.rand.org/pubs/technical_reports/TR1144z1.html; and 2. National Academy of Sciences - National Research Council. *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy*. Washington, D.C.: The National Academies Press, 2011. http://www.nap.edu/catalog.php?record_id=13105.

[9] *Bioenergy - Chances and Limits*. Nationale Akademie der Wissenschaften - Leopoldina, 2012. http://www.leopoldina.org/en/publications/detailview/?publication[publication]=433.

[10] National Research Council - Committee on the Sustainable Development of Algal Biofuels. *Sustainable Development of Algal Biofuels in the United States*. Washington, D.C.: The National Academies Press, October 2012. http://www.nap.edu/catalog.php?record_id=13437.

[11] 10 USC § 2924 - Definitions. December 31, 2011. Contains definitions of "energy security," operational energy," and "renewable energy sources," among others, as specified in the National Defense Authorization Act of 2012. http://www.law.cornell.edu/uscode/text/10/2924?quicktabs_8=1#quicktabs-8.

[12] "How Much Petroleum Does the United States Import and from Where?" *Energy Information Administration*, July 16, 2012. http://www.eia.gov/tools/faqs/faq.cfm?id=727&t=6.

[13] A liter of gasoline contains 116 grams of hydrogen compared to 71 grams per liter in pure liquid hydrogen.

[14] Once ammonia becomes available in the soil or plant roots it can react inorganically with water and oxygen and decomposes into hydrogen gas, hydrogen ions, and nitrate ions in a process known as "nitrification." Partial oxidation of ammonia produces the GHG nitrous oxide (N_2O) and hydrogen gas: $2NH_3 + O_2 \longrightarrow N_2O + H_2O + 2H_2$. Full decomposition of ammonia in water solution with oxygen produces nitric acid and water completing nitrification: $NH_3 + H_2O + 2O_2 \longrightarrow 2H^+ + NO_3^- + OH^- + H_2O$. Nitrification can also be accomplished through the action of *nitrosomas* microbes that break down ammonia into nitrite (NO_2^-) to release metabolic energy, and *nitrobacter* microbes that break down nitrite into nitrate (NO_3^-) for metabolic energy. Organisms that have the hydrogenase uptake enzyme (HUP+) can capture and oxidize H_2 into $2H^+ + 2e^-$ and harvest that energy. This includes the *rhizobium*, *azotobacter*, and *cyanobacteria* microbes that live in roots and soil and fix nitrogen. See 1. Z. Dong and D.B. Layzell. "H_2 Oxidation, O_2 Uptake and CO_2 Fixation in Hydrogen Treated Soils." *Plant and Soil* 229, no. 1 (2001): 1–12. http://www.springerlink.com/content/qp73k5770103075r/abstract/. Thus the hydrogen from soil ammonia is fueling the symbiotic soil- plant biome even before any nitrate nitrogen is taken up by the plant. See 2. Stein et al. "Microbial Activity and Bacterial Composition of H_2-treated Soils with Net CO_2 Fixation." *Soil Biology and Biochemistry* 37, no. 10 (October 2005): 1938–1945; 3. Ducat et al. "Rewiring Hydrogenase-dependent Redox Circuits in Cyanobacteria." *Proceedings of the National Academy of Sciences* 108, no. 10 (March 8, 2011): 3941–3946. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3053959/; and 4. Simpson and Burris. "A Nitrogen Pressure of 50 Atmospheres Does Not Prevent

Evolution of Hydrogen by Nitrogenase." *Science* 224, no. 4653 (June 8, 1984): 1095–1097. http://www.sciencemag.org/cgi/doi/10.1126/science.6585956.

[15] These molecular fractions are based on ultimate analysis mass fractions of 32 species of cultivated biomass which yielded averages of of 47.9% carbon, 5.7% hydrogen, 41.1% oxygen, 0.5% nitrogen, and 4.8% other elements.

[16] These processes include the ATP-ADP, NAD-NADH, and FAD-$FADH_2$ reactions that power photosynthesis and cellular metabolism.

[17] There are several competing formulae for approximating the combustion higher heating values (HHV) of biomass: Boie, Dulong, Mason and Gandhi, Gaur and Reed, Channiwala, etc. All agree that hydrogen and carbon carry the preponderance of the potential combustion energy and that the presence of nitrogen and oxygen in the fuel actually decrease the energy density. See 1. Gaur and Reed. *An Atlas of Thermal Data For Biomass and Other Fuels*. National Renewable Energy Laboratory, June 1995. http://www.nrel.gov/docs/legosti/old/7965.pdf. Coefficients for calculating HHV in MJ/kg by applying the ultimate analysis mass fraction of each element = (+1.1783 x H) + (+0.3491 x C) + (+0.1005 x S) + (-0.0151 x N) + (-0.1034 x O) + (-0.0211 x (K + other minerals)) per S. A. Channiwala, "On Biomass Gasification Process and Technology Development - Some Analytical and Experimental Investigations." Ph.D. thesis, IIT Bombay, Mumbai, 1992.

[18] Reforming CO_2 and H_2O into simple sugar follows the stoichiometry: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6$ (glucose), with a change in enthalpy (ΔH) of $\approx$ 2.8 MJ/mol. ΔH for methane combustion of the same molecular mass ($3CH_4 + 6O_2 \rightarrow 3CO_2 + 6H_2O$) is $\approx$ -2.6 MJ/mol. Fossil fuel, after being geologically processed from plant or animal carbohydrates into hydrocarbons, still retains more than 90% of the photosynthesis energy of the original ancient biomass, and the only cost to civilization to get this concentrated energy is extracting it form the ground and refining it. The huge amount of energy already input by the earth for free to transform solid biomass into liquid fuel is why biofuels have such a hard time competing with fossil fuels. See "Photosynthesis." GenChem Textbook, n.d. http://chemed.chem.wisc.edu/chempaths/GenChem-Textbook/Photosynthesis-979.html.

[19] The widely accepted value for "biomass accumulation efficiency," which is the fraction of total incident solar energy converted into biomass by photosynthesis, is 0.1% for most terrestrial plants. Plants actually make use of a much higher fraction of the sun's energy, but most of it goes into overhead costs such as evaporating water from the leaves to perform the work of drawing up nutrients from the ground against the force of gravity. Efficiencies as high as 4% under

special circumstances have been reported, and it may be possible to boost this to 8% in laboratory conditions with human reengineering of the enzymes and mechanics. However, the highest efficiencies are achieved at very low light fluxes. Photosynthesis is saturated in capacity between 20% and 50% of maximum solar irradiance, and plants suffer radiation damage at these higher levels. Gains in net biomass accumulation remain elusive. See 1. Zhu et al. "What Is the Maximum Efficiency with Which Photosynthesis Can Convert Solar Energy into Biomass?" *Current Opinion in Biotechnology* 19, no. 2 (April 2008): 153–159. http://linkinghub.elsevier.com/retrieve/pii/S0958166908000165; 2. Blankenship et al., "Comparing Photosynthetic and Photovoltaic Efficiencies and Recognizing the Potential for Improvement." *Science* 332, no. 6031 (May 12, 2011): 805–809; 3. Michel. "The Nonsense of Biofuels." *Angewandte Chemie International Edition* 51, no. 11 (March 12, 2012): 2516–2518. http://doi.wiley.com/10.1002/anie.201200218; and 4. "Renewable Biological Systems for Alternative Sustainable Energy Production: Chapter 1 - Biological Energy Production." *Food and Agriculture Organization of the United Nations*, September 7, 2012. http://www.fao.org/docrep/w7241e/w7241e05.htm#1.2.1. For aquatic photosynthesis, see 5. Weyer et al. "Theoretical Maximum Algal Oil Production." *BioEnergy Research* 3, no. 2 (October 8, 2009): 204–213. http://www.springerlink.com/index/10.1007/s12155-009-9046-x.

[20] The National Renewable Energy Laboratory reports that solar radiation across the spectrum delivers energy to the cloudless southwestern US desert at a rate of 7.25 kWh/m^2-day = 302 W/m^2. At the observed biomass accumulation efficiency of 0.1%, this equates to 0.3 W/m^2 put into plant biomass, of which only a fraction can be eventually recovered as liquid fuel. See 1. "Concentrating Solar Resource: Direct Normal - Annual". National Renewable Energy Laboratory, February 2009. http://www.nrel.gov/gis/images/map_csp_us_10km_annual_feb2009.jpg.

[21] Solar photo-voltaic (PV) AC power density of 6.0 W/m^2 is the current real-world best-case for large solar farm sites in optimal US locations. This value is based on empirical analysis of nearly five years of actual performance of the Nellis AFB solar power plant (Dec 2007 completion, $100M, 72,416 panels on 140 acres, 14MW$_{pv}$ (13MW$_{ac}$) nameplate capacity, single-axis tracking array, 19% land coverage density, 24.5% capacity factor, producing 30 GWh/yr). See 1. "Nellis AFB Solar Power System". *U.S. Air Force*, accessed August 22, 2012. http://www.nellis.af.mil/shared/media/document/AFD-080117-043.pdf; and 2. "SunPower Monitor - Nellis Air Force Base." *Sunpower Performance Monitoring*, August 2012. http://commercial.sunpowermonitor.com/Commercial/kiosk.aspx?id=1dd14d57-7840-4b2d-af0a-0fe0fdd5c872.

[22] "Nitrogen-fixing" should really be known as "ammonia-fixing." Most agricultural literature completely bypasses any mention of hydrogen as a fertilizer component and instead focuses exclusively on nitrogen or "N." This dates from the days before widespread use of synthetic ammonia when nitrogen was exclusively applied in mineral salt form as sodium nitrate ($NaNO_3$) or potassium nitrate (KNO_3) without any of the hydrogen energy carriers of the ammonia-based forms. If soil is deficient in nitrogen, then adding this critical nutrient in mineral or ammoniacal form will improve crop health and yield. However, applying mineral nitrogen above the necessary nutrient level is less effective and can even be poisonous to plants. Only recently has hydrogen been explicitly recognized as a fertilizer in its own right. Crops respond with dramatically increased yields to energy supplied in any form of the ammonia molecule including anhydrous ammonia (NH_3), the ammonium ion (NH_4^+), and urea ($(NH_2)_2CO$). In each of these molecules, the hydrogen atoms are also energy carriers and greatly outnumber the nitrogen. Studies have also shown that fertilizing with pure hydrogen gas (H_2) without adding any nitrogen at all can greatly boost soil bacteria activity and plant biomass synthesis. See 1. Dong and Layzell. "H_2 Oxidation, O_2 Uptake and CO_2 Fixation in Hydrogen Treated Soils." *Plant and Soil* 229, no. 1 (2001): 1–12. http://www.springerlink.com/content/qp73k5770103075r/abstract/. Seventy-five percent of the beneficial effect of legumes on crop rotation is not explainable by nitrogen nutrition and is now believed to be due to residual hydrogen in the soil. See 2. Dean et al. "Soybean Nodule Hydrogen Metabolism Affects Soil Hydrogen Uptake and Growth of Rotation Crops." *Canadian Journal of Plant Science* 86, no. Special Issue (December 2006): 1355–1359. http://pubs.aic.ca/doi/abs/10.4141/P06-082; and 3. Dong et al. "Hydrogen Fertilization of Soils - Is This a Benefit of Legumes in Rotation?" *Plant, Cell and Environment* 26, no. 11 (November 2003): 1875–1879. http://doi.wiley.com/10.1046/j.1365-3040.2003.01103.x. Applying hydrogen-rich ammonia fertilizer to crops that are robust nitrogen fixers such as soy still results in substantial gains. See 4. Ferguson et al. "Fertilizer Recommendations for Soybean." University of Nebraska Institute of Agriculture and Natural Resources, August 2006. http://www.ianrpubs.unl.edu/live/g859/build/g859.pdf. Further evidence of hydrogen's efficacy in boosting biosynthesis is the observed preferential uptake of ammonium ($NH_4^{+)}$ versus nitrate (NO_3^-) by plants and phytoplankton. See 5. Jackson et al. "Roots, Nitrogen Transformations, and Ecosystem Services." *Annual Review of Plant Biology* 59, no. 1 (2008): 341–363. http://www.annualreviews.org/doi/abs/10.1146/annurev.arplant.59.032607.092932; and 6. Dortch, Quay. "The Interaction Between Ammonium and Nitrate Uptake in Phytoplankton." *Marine Ecology Progress Series* 61 (March 8, 1990): 183–201. http://www.int-res.com/articles/meps/61/m061p183.pdf.

[23] Symbiotic rhizobial root bacteria get sugar from the host plant and use some of that energy and hydrogen to create NH_3 and H_2 gas and release these to the plant and into the soil. Soil bacteria metabolize the soil ammonia and H_2 and use that energy to break down soil minerals and materials such as chitin and lignin in

humus into mineral nutrients and energetic reduced carbon usable by the plant. For various aspects of the energy relationship between plants, bacteria, and ammonia, see 1. Mylona et al. "Symbiotic Nitrogen Fixation." *The Plant Cell*, no. 7 (July 1995): 869–885. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC160880/; 2. Hayat et al. "Soil Beneficial Bacteria and Their Role in Plant Growth Promotion: a Review." *Annals of Microbiology* 60, no. 4 (August 28, 2010): 579–598. http://u-tokyo.academia.edu/IFTIKHARAHMED/Papers/293426/Soil_Beneficial_Bacteria_and_Their_Role_In_Plant_Growth_Promotion_a_Review; 3. Sanguinetti et al. "MMG: a Probabilistic Tool to Identify Submodules of Metabolic Pathways." *Bioinformatics* 24, no. 8 (February 21, 2008): 1078–1084. http://bioinformatics.oxfordjournals.org/cgi/doi/10.1093/bioinformatics/btn066; and 4. Matiru and Dakora. "Potential Use of Rhizobial Bacteria as Promoters of Plant Growth for Increased Yield in Landraces of African Cereal Crops." *African Journal of Biotechnology* 3, no. 1 (2004): 1–7. http://www.ajol.info/index.php/ajb/article/view/14908.

[24] Gibson et al. "Origin, History and Uses of Corn." *Iowa State University Department of Agronomy*, January 2002. http://www.agron.iastate.edu/courses/agron212/readings/corn_history.htm.

[25] Worrell et al. *Energy Use and Energy Intensity of the US Chemical Industry*. Lawrence Berkeley National Laboratory, April 2000.

[26] *Mineral Commodity Summaries 2012*. US Geological Survey, January 24, 2012. http://minerals.usgs.gov/minerals/pubs/mcs/.

[27] Hydrogen-free sodium-nitrate fertilizer ($NaNO_3$) comprised only 0.046% of commercial nitrogen fertilizer use in 2010 (13,000 of 28,000,000 tons). "Fertilizer Use and Price." USDA Economic Research Service, May 4, 2012. http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx.

[28] Gibson et al.

[29] Blackmer et al. "Nitrogen Fertilizer Recommendations for Corn in Iowa". *Iowa State University*, May 1997. http://www.extension.iastate.edu/Publications/PM1714.pdf.

[30] Corn grain yield data from 1. "QuickStats Ad-hoc Query Tool." *USDA National Agricultural Statistics Service*, January 28, 2013. http://quickstats.nass.usda.gov/results/53B3BBDE-5AB4-3595-89FC-B691FF3F338E; Ammonia consumption data from 2. "Nitrogen (fixed) - Ammonia Statistics." US Geological Survey, November 10, 2011. http://minerals.usgs.gov/ds/2005/140/ds140-nitro.xls.

[31] Breeding and altered genetics have resulted in many crop improvements such as increased resistance to pests and disease, herbicide tolerance, drought and salt tolerance, freeze resistance, etc. But the principal effect of these alterations is to increase the fraction of planted crop that is ultimately harvested. The maximum yield is bounded by energy input, which is sunlight, reduced carbon, reduced hydrogen, and ammoniacal nitrogen compounds. Field research indicates that without artificial fertilizer, US crop yields would drop at least 50%. Stewart et al. "The Contribution of Commercial Fertilizer Nutrients to Food Production." *Agronomy Journal* 97, no. 1 (2005): 1. https://www.agronomy.org/publications/aj/abstracts/97/1/0001.

[32] Tadeusz W. Patzek, "A Probabilistic Analysis of the Switchgrass Ethanol Cycle," *Sustainability* 2, no. 10 (September 2010), 3158–3194, www.mdpi.com/2071-1050/2/10/3158/.

[33] A large-scale attempt to commercialize jatropha for biodiesel in Southern India produced yields 1/10th of those promised. The crop was a poor fit with the local ecological and socio-economic conditions, and 70% of plantations were uprooted or abandoned, having economically ruined participating farmers. See Slade et al. *Energy from Biomass: The Size of the Global Resource (2011)*. UK Energy Research Centre, 2011. http://www.ukerc.ac.uk/support/tiki-download_file.php?fileId=2095.

[34] Higher volumetric energy density combustion materials include beryllium, aluminum, silicon, carbon, lithium borohydride ($LiBH_4$), hexamine ($C_6H_{12}N_4$), and high-density plastics synthesized from petroleum—all solids.

[35] See 1. *ORNL Ethanol Pipeline Corrosion Literature Study Final Report*. Oak Ridge National Laboratory, May 19, 2008. http://www.ornl.gov/sci/ees/itp/documents/ORNL%20Ethanol%20Pipeline%20Corrosion%20Literature%20Study%20Final%20Report.pdf; and 2. Bunting et al. *Fungible and Compatible Biofuels: Literature Search, Summary, and Recommendations*. Oak Ridge National Laboratory, September 30, 2010.

[36] Higher heating value (HHV) volumetric energy densities of various alternatives (MJ/liter): petroleum diesel (38.3), biodiesel (35.7), jet A-1/JP-8 (34.9), gasoline (34.7), isobutanol (28.9), cryogenic liquid natural gas (23.6), ethanol (23.5), fast pyrolysis bio-oil from wood (21.7), ammonia (12.7), cryogenic liquid hydrogen (10.1), lithium thionyl chloride battery (3.75), methanol fuel cell (1.38), lithium-ion battery (1.33). The lower the number, the proportionately longer the convoy.

[37] Hydrotreatment is most often used as a collective term for a set of processes necessary to refine or upgrade biofuels into true hydrocarbons that are "drop-in" compatible substitutes for conventional hydrocarbon applications. These processes include hydrogenation, deoxygenation, cracking, isomerization, fractionation, and adding additives as necessary to adjust energy density, cetane, octane, volatility, flammability, cold flow properties, lubricity, elastomeric seal compatibility, etc. See Munoz et al. *Production of Renewable Diesel Fuel*. University of Idaho: National Institute for Advanced Transportation Technology, June 2012. http://ntl.bts.gov/lib/46000/46200/46277/KLK766_N12-08.pdf.

[38] Other similar formulations of energy balance ratios include energy return on energy investment (EROEI), energy cost of energy (ECE), energy intensity ratio (EIR) and energy return on investment (ERI). EROI is the most common formulation in the literature, but there is some debate over what boundaries to apply to the formula. What is offered here is the simplest formulation of the concept.

[39] S. A. L. M. Kooijman, *Dynamic energy and mass budgets in biological systems* (Cambridge University Press, 2000).

[40] Timothy Garrett. "How Persistent Is Civilization Growth?" arXiv:1101.5635 (January 28, 2011). http://arxiv.org/abs/1101.5635.

[41] Timothy Garrett, "No way out? The double-bind in seeking global prosperity alongside mitigated climate change," *Earth System Dynamics* 3, no. 1 (January 5, 2012): 1-17.

[42] This author computed EROIs from data provided in Thomas Homer-Dixon, *The Upside of Down: catastrophe, creativity, and the renewal of civilization* (Washington: Island Press, 2006), and additional supporting material made available online at http://www.theupsideofdown.com/rome/colosseum/.

[43] Ibid. EROI for both humans and oxen as the ratio of maximum work output divided by food calorie input was calculated by this author from Homer-Dixon's online data as 0.175:1. EROI for Roman wheat as ratio of food calorie output divided by labor and seed grain inputs was 10.52:1. EROI for alfalfa was 26.99:1. Humans eating wheat yield a heavy labor EROI of 0.175 x 10.52 = 1.84:1. Oxen eating alfalfa yield a heavy labor EROI of 0.175 x 26.99 = 4.72:1. Teaming humans with oxen and applying various reductions for idle time and for those performing light work/skilled labor versus heavy labor according to Homer-Dixon's research gives the overall peak and sustained EROIs of 4.2:1 and 1.8:1 quoted.

[44] This tipping point is also correlated with greater than 10% GDP expenditures on energy. See C. W. King, "Energy intensity ratios as net energy measures of

United States energy production and expenditures," *Environmental Research Letters* 5, no. 4 (October 1, 2010): 044006.

[45] Hall et al., "What is the Minimum EROI that a Sustainable Society Must Have?," *Energies* 2, no. 1 (January 23, 2009): 25-47. The case considered in detail is liquid transportation fuel for modern civilization, which is exactly applicable

[46] Murphy et al., "Year in review—EROI or energy return on (energy) invested," *Annals of the New York Academy of Sciences* 1185, no. 1 (January 1, 2010): 102-118.

[47] X-axis energy contributions are EIA data for 2010 reported in 1. "Estimated U.S. Energy Use in 2010: ~98.0 Quads." Lawrence Livermore National Laboratory, 2011. https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2010/LLNLUSEnergy2010.png. Y-axis EROI values are depicted as ellipses to capture the range of values reported in different studies and for different sites. These values derived from this author's synthesis of published literature review including the following documents: 2. Department of Energy. "Fact Sheet: Energy Efficiency of Strategic Unconventional Resources.pdf." *Fossil Energy*, accessed Jan 29, 2012. http://fossil.energy.gov/programs/reserves/npr/Energy_Efficiency_Fact_Sheet.pdf; 3. Nate Hagens. "Proper Calculation of Brazilian Sugar Cane EROI." *The Oil Drum*, March 24, 2009. http://netenergy.theoildrum.com/node/5183#comment-486247; 4. Guilford et al. "A New Long Term Assessment of Energy Return on Investment (EROI) for U.S. Oil and Gas Discovery and Production." *Sustainability* 3, no. 10 (October 14, 2011): 1866–1887. http://www.mdpi.com//2071-1050/3/10/1866/; 5. Charles A. S. Hall. "Wave & Geothermal." *The Oil Drum*, May 14, 2008. http://www.theoildrum.com/node/3949; 6. ———. "Why EROI Matters." *The Oil Drum*, April 1, 2008. http://www.theoildrum.com/node/3786; 7. ———. "Provisional Results." *The Oil Drum*, April 8, 2008. http://www.theoildrum.com/node/3810; 8. ———. "Unconventional Oil: Tar Sands and Shale Oil." *The Oil Drum*, April 15, 2008. http://www.theoildrum.com/node/3839; 9. ———. "Nuclear Power." *The Oil Drum*, April 22, 2008. http://www.theoildrum.com/node/3877; 10. ———. "Solar, Wind and Hydro." *The Oil Drum*, April 29, 2008. http://www.theoildrum.com/node/3910; 11. Hall et al. "What Is the Minimum EROI That a Sustainable Society Must Have?"; 12. Hall et al. "Seeking to Understand the Reasons for Different Energy Return on Investment (EROI) Estimates for Biofuels." *Sustainability* 3, no. 12 (December 13, 2011): 2413–2432. http://www.mdpi.com/2071-1050/3/12/2413/htm; 13. Hill et al. "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels." *Proceedings of the National Academy of Sciences* 103, no. 30 (2006): 11206; 14. C. W. King. "Energy Intensity Ratios as Net Energy Measures of United States Energy Production and Expenditures." *Environmental Research Letters* 5, no. 4 (October 1, 2010): 044006. http://iopscience.iop.org/1748-9326/5/4/044006; 15. King and Hall. "Relating Financial and Energy Return on Investment." *Sustainability* 3, no. 10 (October 11, 2011): 1810–1832. http://www.mdpi.com//2071-

1050/3/10/1810/; 16. David Murphy. "EROI Update: Alberta Tar Sands Toe-to-Heel Air Injection." *The Oil Drum*, March 18, 2009. http://netenergy.theoildrum.com/node/5183; 17. David Murphy. "The Energy Return on Investment Threshold." *The Oil Drum*, November 25, 2011. http://www.theoildrum.com/node/8625; 18. Murphy et al. "New Perspectives on the Energy Return on (energy) Investment (EROI) of Corn Ethanol." *Environment, Development and Sustainability* 13, no. 1 (July 11, 2010): 179–202. http://www.springerlink.com/index/10.1007/s10668-010-9255-7; 19. Murphy et al. "Order from Chaos: A Preliminary Protocol for Determining the EROI of Fuels." *Sustainability* 3, no. 10 (October 17, 2011): 1888–1907. http://www.mdpi.com/2071-1050/3/10/1888; 20. Tad W. Patzek. "A First-Law Thermodynamic Analysis of the Corn-Ethanol Cycle." *Natural Resources Research* 15, no. 4 (February 22, 2007): 255–270. http://www.springerlink.com/index/10.1007/s11053-007-9026-9; 21. Bruce Pile. "The Alternative Energy No One Is Thinking About." *Seeking Alpha*, accessed January 13, 2012. http://seekingalpha.com/instablog/152129-bruce-pile/7480-the-alternative-energy-no-one-is-thinking-about. 22. Pimentel and Patzek. "Ethanol Production: Energy and Economic Issues Related to U.S. and Brazilian Sugarcane." *Natural Resources Research* 16, no. 3 (August 21, 2007): 235–242. http://www.springerlink.com/index/10.1007/s11053-007-9049-2; 23. Shapouri et al. "Estimating the Net Energy Balance of Corn Ethanol." *Agricultural Economic Report* 721 (July 1995). http://content.imamu.edu.sa/Scholars/it/net/usda_shapouri.pdf.

[48] Corn ethanol EROI values in the literature cluster between 0.7:1 to 1.7:1 with a median value of 1.2:1. Many meta-studies comparing and contrasting multiple EROI approaches and papers have also been performed. This author judges the most thorough and authoritative individual study to be 1. Hill et al., "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels," *Proceedings of the National Academy of Sciences* 103, no. 30 (2006): 11206. This study is one of several to promulgate a value of 1.25:1, and to find that any positive energy balance was entirely dependent upon giving energy credit for co-products. The most thorough and authoritative of the recent meta-studies surveying multiple individual corn ethanol life-cycle analyses was judged to be 2. Murphy et al. "New Perspectives on the Energy Return on (energy) Investment (EROI) of Corn Ethanol." *Environment, Development and Sustainability* 13, no. 1 (July 11, 2010): 179–202. http://www.springerlink.com/index/10.1007/s10668-010-9255-7. This study is actually less favorable and finds a neutral 1:1 EROI. Two USDA-funded studies have found values of 1.24:1 in 1995 and 1.34:1 in 2002: 3. Shapouri et al. "Estimating the Net Energy Balance of Corn Ethanol." *Agricultural Economic Report* 721 (July 1995). http://content.imamu.edu.sa/Scholars/it/net/usda_shapouri.pdf;

and 4. Shapouri et al . *The Energy Balance of Corn Ethanol: An Update*. US Department of Agriculture, July 2002.

[49] Shapouri and Salassi. *The Economic Feasibility of Ethanol Production from Sugar in the United States*. US Department of Agriculture, July 2006. http://www.lsuagcenter.com/NR/rdonlyres/0EF2C03C-1C69-455E-AB51-C16D165C2F41/28608/EthanolSugarFeasibilityReport3Julyreleasedcopy.pdf

[50] See 1. Nate Hagens. "Proper Calculation of Brazilian Sugar Cane EROI." *The Oil Drum*, March 24, 2009. http://netenergy.theoildrum.com/node/5183#comment-486247; and 2. Murphy et al. "Order from Chaos: A Preliminary Protocol for Determining the EROI of Fuels." *Sustainability* 3, no. 10 (October 17, 2011): 1888–1907. http://www.mdpi.com/2071-1050/3/10/1888.

[51] Pimentel et al., "Ethanol Production: Energy and Economic Issues Related to U.S. and Brazilian Sugarcane." *Natural Resources Research* 16, no. 3 (August 21, 2007): 235–242. http://www.springerlink.com/index/10.1007/s11053-007-9049-2.

[52] "Emission Factor Documentation for AP-42 Section 1.8 Bagasse Combustion in Sugar Mills." Environmental Protection Agency, April 1993. http://www.epa.gov/ttn/chief/ap42/ch01/bgdocs/b01s08.pdf.

[53] "Revised Totals for South-Central Brazil Sugarcane Harvest Show Even Smaller Cane Crush for 2011/2012 Season." *SugarCane.org*, November 1, 2011. http://sugarcane.org/media-center/sugarcane-statistics/2011/revised-totals-for-south-central-brazil-sugarcane-harvest2028show-even-smaller-cane-crush-for-2011-2012-season-1.

[54] See 1. Foreign Agricultural Service. *Brazil Biofuels Annual Report 2012*. US Department of Agriculture, August 21, 2012. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_8-21-2012.pdf; and 2. "Short-Term Energy Outlook." *Energy Information Administration*, December 11, 2012. http://www.eia.gov/forecasts/steo/report/renew_co2.cfm.

[55] Patzek. "A Probabilistic Analysis of the Switchgrass Ethanol Cycle."

[56] Questionably optimistic EROI prediction found in 1. M. R. Schmer et al., "Net energy of cellulosic ethanol from switchgrass," *Proceedings of the National Academy of Sciences* 105, no. 2 (January 15, 2008): 464 -469. For a more conservative analysis, and one which has proven to be more predictive, see 2. Pimentel and Patzek, "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower," *Natural Resources Research* 14, no. 1 (March 2005): 65-76.

[57] National Academy of Sciences - National Research Council, *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy*, (Washington, D.C.: The National Academies Press, 2011).

[58] "The Range Fuels Failure." *Biofuels Digest*, December 5, 2011. http://www.biofuelsdigest.com/bdigest/2011/12/05/the-range-fuels-failure/

[59] "Press Releases." *ZeaChem Inc*., accessed October 6, 2012. http://www.zeachem.com/press/pressreleases.php.

[60] Kevin Bullis. "Biofuels Companies Drop Biomass and Turn to Natural Gas." *MIT Technology Review*, October 30, 2012. http://www.technologyreview.com/news/506561/biofuels-companies-drop-biomass-and-turn-to-natural-gas/.

[61] "The October Surprise: BP Cancels Plans for US Cellulosic Ethanol Plant." *Renewable Energy World*, October 26, 2012. http://www.renewableenergyworld.com/rea/news/article/2012/10/the-october-surprise-bp-cancels-plans-for-us-cellulosic-ethanol-plant.

[62] Randy Schnepf, and Brent D. Yacobucci. *Renewable Fuel Standard (RFS): Overview and Issues*. Congressional Research Service, October 14, 2010. http://digital.library.unt.edu/ark:/67531/metadc31329/m1/1/high_res_d/R40155_2010Oct14.pdf.

[63] See 1. "2012 EMTS Data." Environmental Protection Agency, July 19, 2012. http://www.epa.gov/otaq/fuels/rfsdata/2012emts.htm; 2. "Production." Blue Sugars Corporation, accessed October 6, 2012. http://bluesugars.com/technology-production.htm; 3. Sapp, Meghan. "Petrobras, KL Energy Extend Cellulosic Ethanol Development Agreement." *Biofuels Digest*, June 26, 2012. http://www.biofuelsdigest.com/bdigest/2012/06/26/petrobras-kl-energy-extend-cellulosic-ethanol-development-agreement/; and 4. "Federal Register, Volume 77 Issue 5". Government Printing Office, January 9, 2012. http://www.gpo.gov/fdsys/pkg/FR-2012-01-09/html/2011-33451.htm.

[64] For Gevo, see 1. Kevin Bullis. "To Survive, Some Biofuels Companies Give Up on Biofuels." *MIT Technology Review*, December 21, 2011. http://www.technologyreview.com/energy/39371/. For Amyris see 2. Sophie Vorrath. "Biofuels: Have the Republicans Gutted Green Fuel?" *Renew Economy*, May 17, 2012. http://reneweconomy.com.au/2012/biofuels-have-the-republicans-gutted-green-fuel-62642. For Cellana see 3. Jim Lane. "Shell Exits Algae as It Commences a 'Year of Choices'." *Renewable Energy World*, January 31, 2011.

http://www.renewableenergyworld.com/rea/news/article/2011/01/shell-exits-algae-as-it-commences-year-of-choices.

[65] Timilsina et al., *The Impacts of Biofuel Targets on Land-Use Change and Food Supply*. World Bank Development Research Group Environment and Energy Team, December 2010. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2010/12/30/000158349_20101230134933/Rendered/PDF/WPS5513.pdf

[66] Matthew Wald, "Companies Face Fines for Not Using Unavailable Biofuel." *New York Times*, January 9, 2012. http://www.nytimes.com/2012/01/10/business/energy-environment/companies-face-fines-for-not-using-unavailable-biofuel.html.

[67] See 1. Jim Lane. "Coskata Switches Focus from Biomass to Natural Gas; to Raise $100M in Natgas-oriented Private Placement." *Biofuels Digest*, July 20, 2012. http://www.biofuelsdigest.com/bdigest/2012/07/20/coskata-switches-from-biomass-to-natural-gas-to-raise-100m-in-natgas-oriented-private-placement/; and 2. Kevin Bullis, "Biofuels Companies Drop Biomass and Turn to Natural Gas."

[68] "Carbohydrates are not a substitute for oil. I was wrong in that, and I admit it. [They] will never replace oil because the economics don't work. You can't take carbohydrates and convert them into hydrocarbons economically. . . . It's a death blow that that maximum yield is about 30 percent." Alan Shaw (former CEO of Codexis) as quoted in Kevin Bullis, "Biofuels Companies Drop Biomass and Turn to Natural Gas."

[69] For soybean productivity see 1. Robert Wisner. "Soybean Oil and Biodiesel Usage Projections & Balance Sheet". Iowa State University, July 23, 2012. http://www.extension.iastate.edu/agdm/crops/outlook/biodieselbalancesheet.pdf. Peak US soy biodiesel productivity over last five seasons of 502 lb/acre converted from pounds to gallons using density of 7.41 lb/gal. Corn yield of 500 gal/acre-yr is slightly more optimistic than actual corn ethanol yield of 478 gal/acre reported in 2. Mueller, Steffan. "News from Corn Ethanol: Energy Use, Co-Products, and Land Use" presented at the Near-term Opportunities for Bio-refineries Symposium, Champaign IL, October 11, 2010. http://bioenergy.illinois.edu/news/biorefinery/pp_mueller.pdf.

[70] Hill et al.

[71] Keane, Eamon. "Algae Biofuels - Not Sustainable." Seeking Alpha. Accessed January 13, 2012. http://seekingalpha.com/article/185070-algae-biofuels-not-sustainable.

[72] See 1. Pfromm et al. "Sustainability of Algae Derived Biodiesel: A Mass Balance Approach." *Bioresource Technology* 102, no. 2 (January 2011): 1185–1193. http://www.sciencedirect.com/science/article/pii/S0960852410015634. The only exception to the limitations above this author could find in published research is that scientists from Brookhaven National Lab, report that if you feed algae acetate, they will continue to reproduce while still producing oil. The problem is that acetate is a direct synthesis product of petroleum, so the research merely proves that feeding algae a pure oil-based diet causes them to produce more oil. This is a signature example of using petroleum energy to make biofuel with diminished returns. See 2. Fan et al. "Oil Accumulation Is Controlled by Carbon Precursor Supply for Fatty Acid Synthesis in Chlamydomonas Reinhardtii." *Plant & Cell Physiology* (May 28, 2012). doi:10.1093/pcp/pcs082.

[73] National Research Council - Committee on the Sustainable Development of Algal Biofuels. *Sustainable Development of Algal Biofuels in the United States*. Washington, D.C.: The National Academies Press, October 2012. http://www.nap.edu/catalog.php?record_id=13437.

[74] Photosynthetic stoichiometry for typical microalgae: 99.5 CO_2 + 75.5 H_2O + 7.5 $CO(NH_2)_2$ + ½ P_2O_5 (+ sunlight) -> [C_{107} H_{181} O_{45} N_{15} P] + 119.75 O_2 [carbon dioxide + water + urea + phosphate (+ sunlight) -> microalgae + oxygen]. In this example, all of the nitrogen in the microalgae is from urea, and one-sixth of the hydrogen (30 of 181 atoms) is from energetic urea, not inert water. Most algae is grown heterotrophically with some nitrogen, hydrogen, or carbon energy being provided in amoniacal or saccharine form. Autotrophic algae growth requires only CO_2, water, phosphate, micronutrients, and sunlight, but delivers diminished yields. See Frank et al., *Life-Cycle Analysis of Algal Lipid Fuels with the GREET Model*. Argonne National Laboratory: Energy Systems Division, April 2008. http://greet.es.anl.gov/publication-algal_lipid_fuels.

[75] "Solazyme Inc. Form 10-Q". Securities and Exchange Commission, November 8, 2011. http://www.faqs.org/sec-filings/111108/SOLAZYME-INC_10-Q/.

[76] Rapier, Robert. "Visit and Conversation With Executives at Solazyme." *Consumer Energy Report*, October 23, 2011. http://www.consumerenergyreport.com/2011/10/23/visit-and-conversation-with-executives-at-solazyme/.

[77] An EROI of 1.06:1 (317 GJ output v. ~300 GJ input) was reported if sun-dried product algal biomass was burned whole in a furnace extracting a thermodynamically perfect 100% of the HHV with no attempt to convert to a liquid fuel. See 1. Clarens, Andres F., Eleazer P. Resurreccion, Mark A. White, and Lisa M. Colosi. "Environmental Life Cycle Comparison of Algae to Other Bioenergy

Feedstocks." *Environmental Science & Technology* 44, no. 5 (March 2010): 1813–1819. http://pubs.acs.org/doi/abs/10.1021/es902838n. A study that considered the costly biomass-to-liquid fuel conversion step found that the input energy required just to circulate the water in the cultivation ponds/tanks exceeded the output biodiesel fuel energy by a factor of seven. See 2. Murphy et al. "Energy-Water Nexus for Mass Cultivation of Algae." *Environmental Science & Technology* 45, no. 13 (July 2011): 5861–5868.

[78] Frank et al. Total energy to produce one functional unit of algae biodiesel of 2,589,441 BTU v. 219,183 BTU to make on functional unit of conventional low-sulfur diesel = 11.8:1 ratio. Well-to-pump fossil fuel energy costs of 548,329 BTU v. 215,388 BTU yield a ratio of 2.6:1.

[79] Fast pyrolysis bio-oil has a specific gravity of 1.24 compared to .079 for ethanol per Ringer, and Scahill. *Large-Scale Pyrolysis Oil Production: A Technology Assessment and Economic Analysis*. National Renewable Energy Laboratory, November 2006.

[80] Raw bio-oils are not suitable feedstock for current refineries because they are too acidic and require 317 stainless steel cladding. Additional pre-processing must be done before they can be upgraded. See Huber, George W., ed. *Breaking the Chemical and Engineering Barriers to Lignocellulosic Biofuels: Next Generation Hydrocarbon Biorefineries*. Washington, D.C.: National Science Foundation: Chemical, Bioengineering, Environmental, and Transport Systems Division, 2008. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.161.2029&rep=rep1&type=pdf.

[81] The alkalinity of bio-char can only offset about 1/5 of the soil acidity resulting from full ammonia fertilization. Laird et al. "Review of the Pyrolysis Platform for Coproducing Bio-oil and Biochar." *Biofuels, Bioproducts and Biorefining* 3, no. 5 (2009): 547–562. http://onlinelibrary.wiley.com/doi/10.1002/bbb.169/abstract.

[82] The gravimetric energy density of charcoal (C_7H_4O) is 30 MJ/kg. It is a chief ingredient of gunpowder.

[83] 565 million acres of trees in the lower 48 states and 185 million acres in Alaska equals 750 million total acres per U.S. Geological Survey. "Biology: Forest Cover Types." Accessed December 18, 2012. http://www.nationalatlas.gov/mapmaker?AppCmd=CUSTOM&LayerList=opchar%3B2&visCats=CAT-agri,CAT-opchar.

[84] "The Indirect Land Use Change Impact of the Use of Biofuels in the EU." *Institute for European Environmental Policy*, March 2011.

http://www.ieep.eu/assets/786/Analysis_of_ILUC_Based_on_the_National_Renewable_Energy_Action_Plans.pdf.

[85] See 1. Hall et al. "What Is the Minimum EROI That a Sustainable Society Must Have?"; and 2. Murphy et al. "New Perspectives on the Energy Return on (energy) Investment (EROI) of Corn Ethanol." *Environment, Development and Sustainability* 13, no. 1 (July 11, 2010): 179–202. doi:10.1007/s10668-010-9255-7.

[86] See 1. Hall et al., "What is the Minimum EROI that a Sustainable Society Must Have?"; and 2. Murphy et al., "Year in review—EROI or energy return on (energy) invested," *Annals of the New York Academy of Sciences* 1185, no. 1 (January 1, 2010): 102-118.

[87] For a long-term depiction of petroleum EROI, see Guilford et al. "A New Long Term Assessment of Energy Return on Investment (EROI) for U.S. Oil and Gas Discovery and Production." *Sustainability* 3, no. 10 (October 14, 2011): 1866–1887. http://www.mdpi.com//2071-1050/3/10/1866/. Current US petroleum fuel EROIs are estimated between 11:1 and 18:1, and coal EROIs are estimated as high as 80:1, so using 8:1 in this analysis as representative of all fossil fuel inputs to corn ethanol processing is very prejudicial against fossil fuel, and the corn ethanol numbers are likely more negative. For recent oil and coal EROI discussion, see Hall et al. "What Is the Minimum EROI That a Sustainable Society Must Have?"

[88] The term "barrel of energy" is used here to represent a generic unit of energy for relative comparison purposes. The value is more specifically defined as the energy in a barrel of crude oil and has a value of 6.1306 GJ = 1.7029 MWh = 5.8106 MBTU. A barrel of crude oil has virtually the same energy content as a barrel of diesel fuel.

[89] The fraction of crude oil that yields fuels vice feedstocks is based on 1. "What a Barrel of Crude Oil Makes." *Texas Oil & Gas Association*, accessed July 8, 2012. http://www.txoga.org/articles/308/1/WHAT-A-BARREL-OF-CRUDE-OIL-MAKES. On average, 42 gallons of crude oil become 19.5 of gasoline, 9.2 of diesel and heating oil, 4.1 of jet fuel, 2.3 of heavy fuel oil for ships and powerplants, 1.9 in liquefied butane and propane, 1.9 in still gas used within the refinery, 1.8 in coke, 1.3 in asphalt and road oil, 1.2 in petrochemical feedstocks, 0.5 in lubricants, 0.2 in kerosene, and 0.3 in other. 5.1 gallons are non-fuel items with industrial utility. Computing CO_2 emissions from the fossil fuel creation assuming input energy is diesel fuel: 1 bbl x 42 gal/bbl of diesel @ 23.66 lb CO_2/gal for diesel combustion = 944 lb. CO_2 from product fuel combustion: 9 bbl of crude x 42 gal/bbl x 22.99 lb CO_2/gal for crude combustion = 8,690 lb. Total $CO_{2:}$ 944 lb + 8,690 lb = 9,634 lb (counting all fuel and non-fuel carbon on the page = worst case). Input H_2O: 9 bbl x 42 gal/bbl x 6.6 gal/gal = 2,495 gal. Water footprint of petroleum covers all extraction and refining processes including water injection into older oil fields for secondary recovery. Maximum value of 6.6 gallons water per gallon of gasoline is

used to make the calculation as conservative as possible and is based on 2. Wu et al. *Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline - 2011 Update*. Argonne National Laboratory: Energy Systems Division, July 2011.

[90] Figure 5 depicts same net energy output as Figure 4 (i.e., 8 bbl diesel equivalent). Each barrel of diesel equivalent energy input yields energy parity in 1.63 barrels of ethanol plus a 0.25 barrel diesel equivalent net energy profit in co-product of DDGS. Ethanol has 0.615 times the volumetric energy density of diesel, therefore it takes 52 bbl of ethanol to equal the energy in 32 bbl of diesel. Values of 478 gal/acre ethanol yield and 5 lb/gal of ethanol in DDGS yield are per 2008 survey of 90 dry-mill ethanol refineries as reported in 1. Mueller, Steffan. "News from Corn Ethanol: Energy Use, Co-Products, and Land Use" presented at the *Near-term Opportunities for Bio-refineries Symposium*, Champaign IL, October 11, 2010. http://bioenergy.illinois.edu/news/biorefinery/pp_mueller.pdf. Acreage of cornfield required: 52 bbl x 42 gal/bbl = 2,184 gal ÷ 478 gal/acre = 4.57 acre. DDGS co-product: 5 lb/gal x 2,184 gal = 10,920 lb. CO_2 from fuel creation: 32 bbl x 42 gal/bbl x 23.66 lb CO_2/gal diesel = 31,799 lb. No CO_2 is charged for ethanol or DDGS consumption. Conservative calculation of CO_2-equivalent (CO_2e) N_2O emissions from corn fertilization: 2% of 150 lb/acre NH_3 x 4.6 acre = 13.8 lb NH_3 x 82.35% N mass fraction of NH_3 = 11.36 lb of N ÷ 63.64% N mass fraction of N_2O = 17.86 lb of N_2O x 298 multiplier for CO_2 warming potential equivalence = 5,321 lb CO2e. Total CO_2e emissions: 31,799 lb CO_2 + 5,321 lb CO_2e = 37,120 lb CO_2e. H_2O for ethanol: 52 bbl x 42 gal/bbl x 1,220 gal/gal = 2.66 million gal. (U.S. average corn ethanol water footprint per 2. Gerbens-Leenes and Hoekstra. The Water Footprint of Sweeteners and Bio-ethanol from Sugar Cane, Sugar Beet and Maize. Value of Water Research Report Series. UNESCO Institute for Water Education, November 2009. http://www.waterfootprint.org/Reports/Report38-WaterFootprint-sweeteners-ethanol.pdf. H_2O for diesel: 32 bbl x 42 gal/bbl x 6.6 gal/gal = 8,870 gal. Total H_20: 2.66 million gal + .009 million gal = 2.67 million gal.

[91] Hall et al. "Seeking to Understand the Reasons for Different Energy Return on Investment (EROI) Estimates for Biofuels."

[92] For the firmly established correlation between EROI and price, see 1. King and Hall. "Relating Financial and Energy Return on Investment." *Sustainability* 3, no. 10 (October 11, 2011): 1810–1832. doi:10.3390/su3101810; and 2. Murphy, David J., Charles A. S. Hall, and Bobby Powers. "New Perspectives on the Energy Return on (energy) Investment (EROI) of Corn Ethanol." *Environment, Development and Sustainability* 13, no. 1 (July 11, 2010): 179–202. doi:10.1007/s10668-010-9255-7.

[93] The pure corn ethanol EROI can be derived by dividing the petroleum-corn ethanol hybrid EROI of 1.25:1 by the pure petroleum EROI of 8:1 discussed earlier to yield 0.156:1 = 1:6.4.

[94] An alternative source of hydrogen is electrolysis from water. This could only be done with massive new sources of electrical power. Using hydroelectric power to electrolyze hydrogen was promoted 100 years ago by Nikola Tesla. If such excess power capacity was available today, we would use the resulting hydrogen directly as fuel and dispense with biofuels, not redirect hydrogen into the less efficient process of making fertilizer for growing biomass for conversion into fuel. This is exactly the same argument for not wasting fossil fuels for this purpose.

[95] Galouchko, Ksenia. "Ethanol Follows Gasoline Higher After Iran Blocks Base Access." *Bloomberg*, February 22, 2012. http://www.bloomberg.com/news/2012-02-22/ethanol-follows-gasoline-higher-after-iran-blocks-base-access.html.

[96] Wilson, Conrad. "High Corn Prices Force Ethanol Plant Shutdowns." *MPR News*, August 28, 2012. http://minnesota.publicradio.org/display/web/2012/08/28/business/agriculture-ethanol-drought/.

[97] Similar graph using US government data available at "Alternative Fuels Data Center." Department of Energy, October 2012. http://www.afdc.energy.gov/data/tab/all/data_set/10323.

[98] For a plot of US ethanol production that follows a perfect Hubbert curve, see "Alternative Fuels Data Center." Department of Energy, October 2012. http://www.afdc.energy.gov/data/tab/all/data_set/10323. Demand-side issues that were ignored by Hubbert are as important in shaping production peaks as supply-side issues such as scarcity. This author has found that a logistic curve (classic sigmoid) with an inflection point in 1945 fits US oil production data from its inception in1859 through the global price collapse of 1986 better than a Hubbert curve (symmetrical sigmoid). The underlying competitive dynamics which drive logistic curves (market share, market penetration, carrying capacity, etc.) also better explain why global crude oil production continues to grow slowly rather than falling off symmetrically as would be the case if increasing scarcity of supply was the dominant factor.

[99] US federal government required production of 13.2 billion gallons of corn ethanol in 2012 for gasoline blending per Environmental Protection Agency, "2012 Renewable Fuel Standards; Final Rule," Vol. 77. 5th ed. *Federal Register*, 2012. http://www.gpo.gov/fdsys/pkg/FR-2012-01-09/pdf/2011-33451.pdf. While the mandate for 2013 increases to 13.8 billion gallons, the additional margin and more

is likely to be met with accumulated Renewable Energy Credits (REC). US corn ethanol biorefineries have been losing money on each gallon of ethanol since July 2012 because of falling oil prices due to increased global production and rising corn prices due to the drought.

[100] See 1. King, C. W. "Energy Intensity Ratios as Net Energy Measures of United States Energy Production and Expenditures." *Environmental Research Letters* 5, no. 4 (October 1, 2010): 044006; and 2. King and Hall. "Relating Financial and Energy Return on Investment." *Sustainability* 3, no. 10 (October 11, 2011): 1810–1832.

[101] Leonnig et al. "Obama Green-tech Program That Backed Solyndra Struggles to Create Jobs." *The Washington Post*, September 15, 2011, sec. Business. http://www.washingtonpost.com/politics/obama-green-tech-program-that-backed-solyndra-struggles-to-create-jobs/2011/09/07/gIQA9Zs3SK_story.html.

[102] "Operational Energy Strategy". *Department of Defense*, May 2011. http://energy.defense.gov/Operational_Energy_Strategy.pdf.

[103] David Miller. "Biofuels Conference: Secretary of the Navy Says Military Can Lead the Way in Alternative Energy." *The Dispatch*. Starkville MS, October 7, 2011. http://www.cdispatch.com/news/article.asp?aid=13418.

[104] $25.73 per gallon for Amyris direct sugar-to-hydrocarbon diesel (DSH) biofuel x 42 gallon/barrel = $1,080.66 per barrel. Highest price paid by Navy was $4,454.55 per gallon = $187,091.10 per barrel. See Table 1 for details.

[105] Contract quantity and price data pulled from official government websites in 2012 and tabulated by contract number in Table 1. Sources include 1. General Services Administration Federal Procurement Data System - Next Generation search page, https://www.fpds.gov/fpdsng_cms/; 2. FedBizOpps.gov website search page. https://www.fbo.gov/; 3. "Bulk Petroleum Contract Awards." *Defense Logistics Agency – Energy*. http://www.energy.dla.mil/bulk_petroleum/Pages/Contract_Awards.aspx; and 4. *DLA Energy Fact Book FY2011.* Defense Logistics Agency - Energy, 2011. http://www.energy.dla.mil/energy_enterprise/Documents/Fact%20Book%20FY2011%20Rev.pdf.

[106] Nerurkar, Neelesh. *US Oil Imports: Context and Considerations*. Congressional Research Service, April 1, 2011. https://opencrs.com/document/R41765/.

[107] See 1. *Direct Federal Financial Interventions and Subsidies in Energy in Fiscal Year 2010*. Energy Information Agency, July 2011. http://www.eia.gov/analysis/requests/subsidy/; and 2. Annual Energy Review 2011. http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf. Subsidy amounts

for energy sources in Table ES2 from the first reference are divided by 2010 data for US energy production for the respective sources from the second reference.

[108] US Department of Energy, "DOE Recovery Act Funding," *Energy.gov*, December 2011, http://energy.gov/sites/prod/files/recoveryactfunding.xls.

[109] Mabus, Chu, and Vilsack. "Memorandum of Understanding Between the Department of the Navy and the Department of Energy and the Department of Agriculture," June 28, 2011. http://www.rurdev.usda.gov/SupportDocuments/DPASignedMOUEnergyNavyUSDA.pdf.

[110] "AAA's. Daily Fuel Gauge Report." *American Automobile Association*, July 19, 2012. http://fuelgaugereport.opisnet.com/index.asp.

[111] A gallon of ethanol contains only 2/3 the energy of a gallon of gasoline; if priced at energy parity, it would be 2/3 the price. 2010 average retail gasoline price (minus 18.4 cent/gal federal excise tax) = $2.58/gal x 2/3 = $1.72/gal (what ethanol should have cost). 2010 average retail E85 price = $2.40/gal (what retail ethanol did cost to a close approximation). How much consumers overpaid at pump = $2.40/gal – $1.72/gal = $0.68/gal x 12 billion gal blended in 2010 = $8.1 billion. For 2010 fuel prices and $6.1 billion in tax credits see Table 17-1 and footnotes in Office of Management and Budget. *Budget of the U.S. Government: Analytical Perspective Fiscal Year 2012.* Executive Office of the President, 2011; and Table A12 of *Annual Energy Outlook 2012*. Energy Information Agency, June 2012. http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf.

[112] Hargreaves, Steve. "Gasoline: The New Big U.S. Export." *CNN Money*, December 5, 2011. http://money.cnn.com/2011/12/05/news/economy/gasoline_export/index.htm.

[113] See note 105 above.

[114] 2009 tax data is presented as it is the most recent made available by EIA. 2009 was a particularly bad year for IRS revenue from oil company taxes because of the economic crash, and 2010 data is likely much higher. Oil companies paid $13.7 billion in corporate taxes and consumers paid $42.4 billion in excise taxes for a total of $56.1 billion in federal government revenues per "EIA Financial Reporting System Survey - Form EIA-28 Schedule 5112 - Analysis of Income Taxes." *Energy Information Agency*, 2009. ftp://ftp.eia.doe.gov/pub/energy.overview/frs/s5112.xls. Dividing $56.1 billion by the 6.23 billion barrels of oil and gas domestically produced in 2010 yields $9.01

per barrel. Federal excise taxes paid by consumers at the pump are 18.4 cents per gallon for gasoline and 24.4 cents per gallon for diesel.

115 "Market Cap Stock Rankings for Major Integrated Oil & Gas Industry." *YCharts*, January 7, 2013. http://ycharts.com/rankings/industries/Major%20Integrated%20Oil%20&%20Gas/market_cap.

116 "GDP." World Bank, 2011. http://data.worldbank.org/indicator/NY.GDP.MKTP.CD.

117 Annual Energy Review 2011. Energy Information Agency, September 27, 2012. http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf.

118 Slade et al.

119 See note 21 for solar power density derivation. Wind power density of 1.13 W/m^2 based on recent NREL data reporting 2.9 W/m^2 peak and 39% capacity factor as averaged across 2000-2009 US installations with nameplate capacity > 20MW). See 1. Denholm et al. *Land-Use Requirements of Modern Wind Power Plants in the U.S.* National Renewable Energy Laboratory, August 2009. www.nrel.gov/docs/fy09osti/45834.pdf. Corn ethanol power density of 0.315 W/m^2 based on 500 gal/acre-yr @ 76,321 BTU/gal LHV. Soy biodiesel power density of 0.069 W/m^2 based on 70 gal/acre-yr @ 119,545 BTU/gal LHV. Average US crude oil well in 2011 produced 10.6 barrels crude oil per day @ 129,667 BTU/gal on a two-acre parcel of land, which equates to ~90 W/m^2. See 2. *Annual Energy Review 2011*. http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf.

120 Patzek. "A Probabilistic Analysis of the Switchgrass Ethanol Cycle."

121 Jeavons, John. *How to Grow More Vegetables: And Fruits, Nuts, Berries, Grains and Other Crops Than You Ever Thought Possible on Less Land Than You Can Imagine*. 6th ed. Ten Speed Press, 2004.

122 DoE NREL research has calculated the best case for algae yields from pure solar energy without fossil fuel or sugar energy augmentation to be 6,500 gal/acre-yr biodiesel = 17.8 gal/acre-day = 6.42 W/m^2 LHV. Sapphire Energy projects it will achieve 14 gal/acre-day of algae biodiesel from 300 acres by 2014. See 1. "In Race to Algae Fuel, Sapphire Scores Point for Open Ponds." Sapphire Energy, September 6, 2012. http://www.sapphireenergy.com/news-article/1135734-in-race-to-algae-fuel-sapphire. Algenol, using cyanobacteria animal algae instead of microphyte plant algae, and producing ethanol instead of lipids, recently announced it achieved 21.9 gal/acre-day of ethanol. This is equivalent to 5.6 W/m^2 and still

below today's PV solar. See 2. Woods, Paul. "About Algenol." Algenol Biofuels, September 27, 2012. http://www.algenolbiofuels.com/.

[123] See 1. Perlack et al. US Department of Agriculture and Department of Energy. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-ton Annual Supply*. Oak Ridge, TN: Oak Ridge National Laboratory, 2005. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA436753; and 2. R.D. Perlack and B.J. Stokes (leads). US Department of Energy. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*. Oak Ridge, TN: Oak Ridge National Laboratory, 2011. http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf.

[124] Jennifer Franco et al. "The Global Land Grab: A Primer". Transnational Institute, October 11, 2012. http://www.tni.org/primer/global-land-grab.

[125] "Home." *Blue Sugars Corporation*. Accessed October 8, 2012. http://bluesugars.com/index.htm.

[126] Haddok, Eitan. "Biofuels Land Grab: Guatemala's Farmers Lose Plots and Prosperity to 'Energy Independence'." *Scientific American*, January 13, 2012. http://www.scientificamerican.com/article.cfm?id=biofuels-land-grab-guatemala.

[127] Deininger, Klaus W, Derek Byerlee, and World Bank. *Rising Global Interest in Farmland: Can It Yield Sustainable and Equitable benefits?* Washington, D.C.: World Bank, 2011. http://siteresources.worldbank.org/INTARD/Resources/ESW_Sept7_final_final.pdf.

[128] Gallagher, Ed. *The Gallagher Review of the Indirect Effects of Biofuels Production*. East Sussex, UK: Renewable Fuels Agency, July 2008. http://www.unido.org/fileadmin/user_media/UNIDO_Header_Site/Subsites/Green_Industry_Asia_Conference__Maanila_/GC13/Gallagher_Report.pdf.

[129] As biofuel competition with food and the magnitude of GHG released from land use change to cultivation have become undeniably apparent, advocates of biofuels have shifted their focus away from use of every acre of arable land toward use of "degraded" or "marginal" land. However, as shown, biofuels crops are as energy-hungry as food crops, and if grown on marginal land, their energy yields will be equally marginal. The very concept of degraded land is also questionable. To the extent that the ingredients necessary for life exist on a parcel of land, life is already there fixing carbon in the soil and in its biomass as fast as it can. Even the most barren plot of land is covered with the dormant seeds and spores of life just

waiting for the water or other missing ingredient to appear or the toxin levels to subside. Unless reclaiming the Sahara and Gobi and Antarctic deserts or urban parking lots, new crops are always going to displace some other species that was there first already taking full advantage of the available sun and soil energy to sequester carbon.

[130] 1. IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, prepared by the National Greenhouse Gas Inventories Programme [Institute for Global Environmental Strategies (IGES), Tokyo, Japan, 2007. 2. Searchinger et al. "Fixing a Critical Climate Accounting Error." *Science* 326, no. 5952 (October 23, 2009): 527–528. http://www.sciencemag.org/content/326/5952/527.

[131] For seven examples of recent studies finding biofuels increase GHG and environmentally damaging emissions, see 1. Jaeger and Egelkraut. "Biofuel Economics in a Setting of Multiple Objectives and Unintended Consequences." *Renewable and Sustainable Energy Reviews* 15, no. 9 (December 2011): 4320–4333. http://www.sciencedaily.com/releases/2011/11/111129123255.htm; 2. Yang et al. "Replacing Gasoline with Corn Ethanol Results in Significant Environmental Problem-Shifting." *Environmental Science & Technology* (March 14, 2012): 120314152159007. http://pubs.acs.org/doi/abs/10.1021/es203641p; 3. Smith and Searchinger. "Crop-based Biofuels and Associated Environmental Concerns." *GCB Bioenergy* (June 2012). http://www.sciencedaily.com/releases/2012/06/120608100548.htm; 4. Thomas Walker et al. *Biomass Sustainability and Carbon Policy Study*. Manomet Center for Conservation Sciences, June 2010. http://www.manomet.org/sites/manomet.org/files/Manomet_Biomass_Report_Full_LoRez.pdf; 5. Scharlemann et al., "How Green Are Biofuels?," *Science* 319, no. 5859 (January 4, 2008): 43-44; 6. "Alternative Fuels and Advanced Vehicles Data Center: E10 Emissions." *Department of Energy*, January 28, 2011. http://www.afdc.energy.gov/afdc/vehicles/emissions_e10.html; and 7. Hill et al.

[132] Hitz, S. "The Role of Oxygenated Fuel in California Air Quality." University of California, 1999. https://bren.ucsb.edu/research/1999Group_Projects/airquality/airquality_final.pdf.

[133] See 1. Franklin et al. "Clearing the Air: Using Scientific Information to Regulate Reformulated Fuels." *Environmental Science & Technology* 34, no. 18 (September 1, 2000): 3857–3863. http://dx.doi.org/10.1021/es0010103; 2. Rask, Kevin. "Clean Air Policy and Oxygenated Fuels: Do We Get What We Pay For?" *Energy Economics* 26, no. 1 (January 2004): 161–177. doi:10.1016/S0140-9883(03)00040-9; and 3. *AQIRP Final Report*. Auto/Oil Air Quality Improvement Research Program, January 1997. http://www.crcao.com/reports/auto-oil/Default.htm.

[134] MTBE = Methyl Tertiary Butyl Ether, a fuel oxygenate hastily mandated by the EPA to achieve 1990 Clean Air Act standards, but which had the unfortunate side-effect of increasing groundwater fuel contamination. EPA is responsible for air, soil, and groundwater quality, but still has not connected the dots for ethanol across these domains.

[135] Blue Ribbon Panel on Oxygenates. *Achieving Clean Air and Clean Water*. Environmental Protection Agency, September 15, 1999. http://www.epa.gov/oust/mtbe/brp_usts.htm.

[136] American Institute of Physics. "Mixing Processes Could Increase the Impact of Biofuel Spills on Aquatic Environments." *Phys.Org*, November 16, 2012. http://phys.org/news/2012-11-impact-biofuel-aquatic-environments.html.

[137] Energy content of the ethanol-blended gasoline is reduced 3.3% for E10 and 28% for E85, and this roughly corresponds to reduced MPG.

[138] 42 USC § 7545(h)(4) – Regulation of Fuels. "Ethanol waiver: For fuel blends containing gasoline and 10 percent denatured anhydrous ethanol, the Reid vapor pressure limitation under this subsection shall be one pound per square inch (psi) greater than the applicable Reid vapor pressure limitations."

[139] Blue Ribbon Panel on Oxygenates.

[140] Lewis, Jonathan. *Leaping Before They Looked: Lessons from Europe's Experience with the 2003 Biofuels Directive*. Boston: Clean Air Task Force, October 2007.

[141] In 2011, OECD nations reduced CO2 emissions by 0.6% while non-OECD nations increased CO2 emissions by 6.1%, for a net global increase of 3.2% to a record high of 31.6 billion metric tons ~ 35 billion short tons. See "Global Carbon-dioxide Emissions Increase by 1.0 Gt in 2011 to Record High." International Energy Agency, May 24, 2012. http://www.iea.org/newsroomandevents/news/2012/may/name,27216,en.html.

[142] Ibid.

[143] Annual Energy Review 2011.

[144] Davidson et al. *Excess Nitrogen in the U.S. Environment: Trends, Risks, and Solutions*. Ecological Society of America, Winter 2012. http://www.esa.org/science_resources/issues/FileEnglish/issuesinecology15.pdf.

[145] International Panel on Climate Change. *Climate Change 2007: The Physical Science Basis*. Cambridge University Press, 2007. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm.

[146] "Recent Greenhouse Gas Concentrations." Carbon Dioxide Information Analysis Center, February 2012. http://cdiac.ornl.gov/pns/current_ghg.html.

[147] Ravishankara et al. "Nitrous Oxide (N2O): The Dominant Ozone-Depleting Substance Emitted in the 21st Century." *Science* 326, no. 5949 (August 27, 2009): 123–125. http://www.sciencemag.org/cgi/doi/10.1126/science.1176985.

[148] Crutzen et al. "N2O Release from Agro-biofuel Production Negates Global Warming Reduction by Replacing Fossil Fuels." *Atmospheric Chemistry and Physics Discussions* 7, no. 4 (2007): 11191–11205.

[149] According to a nine-nation jointly funded study, if all European governments follow through with their current renewable fuel plans, it will require the conversion to biofuels cultivation of a land area between the size of Belgium and the size of Ireland, and will generate between 81% and 167% more GHG emissions than using straight fossil fuels. See Bowyer, Catherine. "The Indirect Land Use Change Impact of the Use of Biofuels in the EU." *Institute for European Environmental Policy*, March 2011. http://www.ieep.eu/assets/786/Analysis_of_ILUC_Based_on_the_National_Renewable_Energy_Action_Plans.pdf. Also see 1. Righelato et al., "Carbon Mitigation by Biofuels or by Saving and Restoring Forests?," *Science* 317, no. 5840 (2007): 902.

[150] Energy Independence and Security Act of 2007– Section 526. "No Federal agency shall enter into a contract for procurement of an alternative or synthetic fuel, including a fuel produced from nonconventional petroleum sources, for any mobility related use, other than for research or testing, unless the contract specifies that the lifecycle greenhouse gas emissions associated with the production and combustion of the fuel supplied under the contract must, on an ongoing basis, be less than or equal to such emissions from the equivalent conventional fuel produced from conventional petroleum sources." "No later than Oct. 1, 2015, and for each year thereafter, each Federal agency shall achieve ≥ 20 percent reduction in annual petroleum consumption and a 10 percent increase in annual alternative fuel consumption, relative to FY2005 baseline."

[151] *The State of Food Insecurity in the World*. Rome: Food and Agriculture Organization of the United Nations, 2011. http://www.fao.org/docrep/014/i2330e/i2330e.pdf.

[152] Timilsina et al. *Biofuels: Markets, Targets and Impacts*. World Bank, July 2010.

[153] FAO, IFAD, IMF, OECD, UNCTAD, WFP, the World Bank, the WTO, IFPRI and the UN HLTF. *Price Volatility in Food and Agricultural Markets: Policy Responses*. World Bank, 2011.

[154] Brown, Lester R. "The New Geopolitics of Food" *Foreign Policy*, May 2011. http://www.foreignpolicy.com/articles/2011/04/25/the_new_geopolitics_of_food.

[155] Lott, Melissa C. "The U.S. Now Uses More Corn For Fuel Than For Feed." *Scientific American*, October 7, 2011. http://blogs.scientificamerican.com/plugged-in/2011/10/07/the-u-s-now-uses-more-corn-for-fuel-than-for-feed/.

[156] Brown.

[157] Pimentel et al. *Report of the Energy Research Advisory Board on Gasohol*. Gasohol Study Group, April 29, 1980.

[158] Gerard Wynn. "U.S. Corn Ethanol Was Not a Good Policy: Gore." Reuters. Athens, November 22, 2010. http://www.reuters.com/article/2010/11/22/us-ethanol-gore-idUSTRE6AL3CN20101122.

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[161] Chris Rhodes. "The Achilles' Heel Of Algal Biofuels: Peak Phosphate." *Forbes*, February 29, 2012. http://www.forbes.com/sites/energysource/2012/02/29/the-achilles-heel-of-algal-biofuels-peak-phosphate-3/.

[162] *Mineral Commodity Summaries 2012*. US Geological Survey, January 24, 2012. http://minerals.usgs.gov/minerals/pubs/mcs/.

[163] New record highs of 1.65 trillion barrels of proved reserves (1.9% annual increase), and 83.56 million barrels-per-day of production (1.3% annual increase) set in 2011. Reserves have been growing faster than consumption since 1980. See *Statistical Review of World Energy 2012.* British Petroleum, 2012. http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2012.pdf.

[164] Thomas Homer-Dixon.

[165] Gleeson et al. "Water Balance of Global Aquifers Revealed by Groundwater Footprint." Nature 488, no. 7410 (August 9, 2012): 197–200. http://www.nature.com/nature/journal/v488/n7410/full/nature11295.html.

[166] See, 1. Henthorne, Lisa. "The Current State of Desalination." International Desalination Association, November 2009. http://www.idadesal.org/PDF/the%20current%20state%20of%20desalination%20remarks%20nov%2009%20by%20lisa%20henthorne.pdf; and 2. "Water and Oil and Gas." *Desalination.com*, October 8, 2012. http://www.desalination.com/wdr/48/39/and-oil-and-gas.

[167] Padgett, Tim. "The Postquake Water Crisis: Getting Seawater to the Haitians." *Time*, January 18, 2010. http://www.time.com/time/specials/packages/article/0,28804,1953379_1953494_1954584,00.html.

[168] International Data Corporation. "Desalination Industry Enjoys Growth Spurt as Water Scarcity Starts to Bite." *AMEinfo*, September 30, 2012. http://www.ameinfo.com/desalination-industry-enjoys-growth-spurt-water-313351.

[169] Abderrahman, Walid A. *Water Demand Management in Saudi Arabia*. International Development Research Centre, 2001. http://web.idrc.ca/en/ev-93954-201-1-DO_TOPIC.html.

[170] Al Shoaiba and two thirds of Saudi desalination plants in 2000 were multi-stage flash distillation technology, which require about 186 MJ energy input per cubic meter of water output. See Wade, Neil M. "Distillation Plant Development and Cost Update." *Desalination* 136 (September 2000): 3–12. http://www.desline.com/articoli/4051.pdf.

[171] Wu et al. *Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline - 2011 Update*. Argonne National Laboratory: Energy Systems Division, July 2011. Values adjusted by a 2/3 multiplier to correct for the lower energy density of ethanol v. gasoline.

[172] Gerbens-Leenes et al. "The Water Footprint of Bioenergy." *Proceedings of the National Academy of Sciences* 106, no. 25 (June 3, 2009): 10219-10223.

[173] Wade, Neil M. "Distillation Plant Development and Cost Update." *Desalination* 136 (September 2000): 3–12. http://www.desline.com/articoli/4051.pdf.

[174] Barrack Obama. *Executive Order 13603 -- National Defense Resources Preparedness*, March 16, 2012. http://www.whitehouse.gov/the-press-office/2012/03/16/executive-order-national-defense-resources-preparedness.

[175] Carney, Brian M. "The Weekend Interview with Peter Brabeck-Letmathe: Can the World Still Feed Itself?" *The Wall Street Journal*, September 3, 2011. http://online.wsj.com/article/SB10001424053111904787404576529912073080124.html.

[176] "Squeezing Africa Dry: Behind Every Land Grab Is a Water Grab." *GRAIN*, June 11, 2012. http://www.grain.org/article/entries/4516-squeezing-africa-dry-behind-every-land-grab-is-a-water-grab.

[177] The economic value of electric power varies widely across the span of a day and the course of the seasons because of average temperatures and cycles of human activity. The variability in price is often more than a factor of ten between off-peak and peak times (e.g., 2.5 cent/kWh at midnight v. 25.0 cent/kWh at noon). The overall cost of generation decreases toward optimum as power supply online exactly matches power demand, minute-by-minute. Smart grids are a way to attempt to match demand to supply, but matching supply to demand by controlling power generation remains the dominant and essential governor of grid stability. These factors favor dispatchable (controllable) power sources over intermittent (uncontrollable) power sources. Joskow, Paul L. "Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies," February 9, 2011. http://economics.mit.edu/files/6317.

[178] Energy Independence and Security Act of 2007– Section 526.

[179] For two examples of ongoing research to photosynthesize fuel by directly recycling CO_2 and H_2O without making biomass, see 1. Bill Scanlon. "Sun Shines on Old Idea to Make Hydrogen." *Renewable Energy World*, November 5, 2012. http://www.renewableenergyworld.com/rea/news/article/2012/11/sun-shines-on-old-idea-to-make-hydrogen; 2. "Sunshine to Petrol." Sandia National Labs, November 9, 2012. http://energy.sandia.gov/?page_id=776; and 3. "Sunshine-to-Petrol Project Seeks Fuel From Thin Air." *ScienceDaily*, December 10, 2007. http://www.sciencedaily.com/releases/2007/12/071208150135.htm.

[180] Fertilizers with highest H:N ratios from highest to lowest are monoammonium phosphate (MAP), diammonium phosphate (DAP), and ammonium sulfate. All have higher ratios than pure anhydrous ammonia.

[181] "Recent Greenhouse Gas Concentrations." Carbon Dioxide Information Analysis Center, February 2012. http://cdiac.ornl.gov/pns/current_ghg.html.

[182] N_2O and CO_2 have the same molecular mass of 44 Dalton, and their per-ton global warming contributions are in the direct ratio of the global warming potentials

of their molecules (i.e., 298:1). CH_4 has a molecular mass of 16 Dalton and thus there are 44/16 more molecules per ton, each with a 25:1 increase in global warming potential, for a total increase in per-ton global warming potential 69:1.

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University of Waterloo
200 University Avenue West
Waterloo, Ontario